

Shiftwork

An Annotated Bibliography

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This report is an annotated bibliography. The primary purpose of the report was to gather relevant literature from databases with comprehensive coverage. The references cited herein address the design of shiftwork schedules and the effects of shiftwork on safety, health and human performance in many work environments. No limits were placed upon dates of publication; however, the bibliography generally reaches back slightly more than 30 years. No systematic attempt was made to list technical reports from the governments of other countries than the United States, though some are included. Citations listed within and to the publications cited here, along with keywords suggested by these publications, should allow the reader to search an area of interest almost completely. Subjects covered include shiftwork schedule structure; occupational risk and safety in and for aviation operations, driving, health workers, firefighters, maritime operations, military operations, nuclear power industry, police, and rail operations; individual differences, including adaptation and tolerance, age, gender, lark-owl, and locus of control; fatigue countermeasures including light, melatonin, modafinil, napping, and schedule planning; worker health including working hours, cancer, cardiovascular and respiratory, gastrointestinal, hormones and metabolism, reproductive health, and sleep; cognitive performance; models and software; research needs; and measurement methodologies.

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I. INTRODUCTION

There are numerous definitions of “shiftwork.” Generally, work periods that occur outside of (are shifted from) the normal workday hours of about 7 a.m. to 6 p.m are of concern. Following Knauth and Rutenfranz (1976), we may classify the common types of shiftwork as:

- Systems with night work but without weekend work.
- Systems with both night and weekend work, or “continuous shiftwork.” These systems are also called “24/7” systems.

Within the 24/7 domain, we may classify systems as:

- Regular, fixed shifts. Also known as “permanent” shifts.
- Regular, cyclically rotating shifts. For example, four crews and cyclically rotating, 8-hour shifts.
- Irregular, with varying numbers of crews and shift lengths. For example, the 5-day irregular work week of U.S. Federal Aviation Administration air traffic controllers, many nurse work schedules in hospitals, or the irregular schedules flown by air transport crews.

Poorly-scheduled shiftwork induces needless fatigue, causing the human components of an industrial or military system to become the weakest link in the system: the whole system may fail or produce erroneous results because of that weakness. A reasonable shiftwork schedule is the most important factor in minimizing the prevalence of operator error when a 24/7 work demand must be met. Fortunately, we have enough information from many decades of research and application to allow us to create reasonable schedules. Summarizing Miller (2006), there are four main criteria one must meet to be able to create a reasonable shiftwork schedule:

- Have enough people to do the job
- Use four crews
- For regular schedules, use a shift length of either 8 or 12 hours (not including overlap)
- Assure worker satisfaction in terms of predictability, equity, and good-quality time off

Even when one follows this advice, there are known safety issues and known and suspected health issues associated with the extensive exposure to night work that is present in most shiftwork.

II. APPROACH

This report is an annotated bibliography. The primary purpose of the report was to gather relevant literature from databases with comprehensive coverage of shiftwork. The references cited herein address the design of shiftwork schedules and the effects of shiftwork on safety, health, and human performance in many work environments. The cited references were obtained primarily from the U.S. National Library of Medicine (<http://www.ncbi.nlm.nih.gov/pubmed>) and the Defense Technical Informations Center (DTIC), supplemented by material from the National Technical Information Service (NTIS) and other sources. No limits were placed upon dates of publication; however, the bibliography generally reaches back slightly more than 30 years. No systematic attempt was made to list technical reports from the governments of countries other than the United States, although some are included. All references are appropriate for public release.

This bibliography is not presumed to include an exhaustive listing of all relevant publications. However, citations listed within and to the publications cited here, along with keywords suggested by these publications, should allow the reader to search an area of interest almost completely. The section, "Listings of Citations by Subject Matter," provides a quick reference guide to research and development concerning shiftwork. Because the classification of research into somewhat arbitrary categories is inherently inadequate, the reader should search this bibliography for the occurrence of keywords of interest: a citation may not be categorized as expected by the reader. Full references follow the body of the text.

III. LISTINGS OF CITATIONS BY SUBJECT MATTER

The following listing serves as a quick reference guide for this annotated bibliography. The descriptive quotes in this section were selected from the abstracts of the articles and reports. Within each category and subcategory, citations are usually organized from oldest to newest.

A. SHIFTWORK (GENERAL)

Recently, Fido, and Ghali (2008) used questionnaires “to assess quality of sleep, work performance and general health in a sample of 200 males on a schedule of varying 8-hour shifts at the Kuwait Oil Company.” “A matched sample of an equal number of workers on a fixed daytime shift as a control group was enrolled in the study.” Their results indicated “that the majority of workers on an 8-hour variable-shift schedule experienced various health problems, poor quality of sleep and an increased risk for errors and accidents at work as compared with those workers on a straight daytime shift schedule.” These results underscore the fact that:

Shiftworker acquisition, retention and management are difficult problems for supervisors of 24/7 operations. Night work and shiftwork cause quality-of-life problems, *malaise* and fatigue for most people. The problems may take the form of inadequate interactions with the worker’s family and with the worker’s employer. They may also take the form of medical complaints, reduced productivity, high turnover, and high error rates. These responses are initiated by shiftwork-induced disruptions of normal daily and weekly social and physiological cycles. The disruptions diminish safety, productivity, and wellbeing. The basic cause of all of these problems is that humans are not properly designed for night work. Good shiftwork scheduling practices are needed to keep worker malaise and fatigue to a minimum during continuous operations (Miller, 2006, p. 1).

This is a list of some of the many general references concerning shiftwork, listed from older to newer:

- *Shift Work Practices in the United States* (Tasto & Colligan, 1977), an excellent review funded by the National Institute of Occupational Safety and Health.
- Shift work: A review and theoretical analysis (Dunham, 1977)
- *Night Work: Its Effects on the Health and Welfare of the Worker* (Carpentier & Cazamian, 1977)
- Biomedical and psychosocial aspects of shift work. A review (Rutenfranz, Colquhoun, Knauth, & Ghata, 1977). A survey of the different types of shift-work systems in use, and the incidence of shiftwork in different industries and countries, and discussions about health effects and circadian disruption.
- Physiological effects of *rotational* work shifting: a review (LaDou, 1982; Winget, Hughes, & LaDou, 1978).
- *Fourth International Symposium on Night and Shift Work* (Rutenfranz & Colquhoun, 1978). Symposium proceedings, published in *Ergonomics*. Fourteen excellent research papers.

- The 39 chapters in *Studies of Shiftwork* provide a comprehensive picture of research knowledge concerning shiftwork ca. 1980 (Colquhoun & Rutenfranz, 1980). Section headings include:
 - Hours of Work and Shiftwork
 - Biological Adaptation to Shiftwork
 - Individual and Environmental Factors in Adjustment to Shiftwork
 - Effects on Performance Efficiency
 - Effects on Social and Family Life
 - Effects on Health and Well-being
 - The Design of Shift Systems
 - Economics of Shiftwork, and Methods of Compensation
- *The Twenty-Four Hour Workday: Proceedings of a Symposium on Variations in Work-Sleep Schedules* (Johnson, Tepas, Colquhoun, & Colligan, 1980). “The function of this symposium was to bring together workers in three areas that in one way or another, are concerned with a common problem: variations in work-sleep schedules. These three areas are (1) shift work, (2) sleep, and particularly that area concerned with sleep loss and the fragmentation of sleep schedules, and (3) biological rhythms.”
- *Fifth International Symposium on Night and Shift Work* (Reinberg, Vieux, & Andlauer, 1980).
- *Aviation Medicine Translations: Annotated Bibliography of Recently Translated Material* (Simpson & Goulden, 1981). “An annotated bibliography of translations of foreign-language articles is presented. Of the 86 listed entries, 53 are concerned with studies of shift work.”
- *Bibliography of Shift Work Research: 1950-1982* (Schroeder & Goulden, 1983), from the Federal Aviation Administration, in support of research directed at air traffic controller shiftwork schedules.
- “Analysis of 120 shift systems of the police in the Federal Republic of Germany” (Knauth et al., 1983). Includes information on the “frequency distribution of the shift cycles, the duration of shifts, the start and end of shifts, the maximal number of consecutive night shifts, as well as the frequency of different kinds of free weekends.”
- *Psychological Approaches to Night and Shift Work: International Research Papers* (Wedderburn & Smith, 1984). “Twenty papers, presented at the International Commission on Occupational Health’s 1984 Edinburgh Symposium.”
- Lewis (1985) provided “recommendations to the U.S. Nuclear Regulatory Commission (NRC) for an NRC policy on shift scheduling and hours of work (including overtime) for control room operators and other safety-related personnel in nuclear power plants.”
- *Shiftwork Review: Research of the European Foundation, 1981-1984* (Copsey & Corlett, 1986).
- *How to Make Shift Work Safe and Productive* (Monk, 1988). Besides basic information on physiology, scheduling and coping, this book includes chapters on “What Senior Management Ought to Know But Probably Doesn’t” and “What Your Congressman

- Ought to Know But Probably Doesn't."
- The 13 chapters in *Shiftwork*, a "State of the Art Review" from the journal, *Occupational Medicine*, provides a good picture of research knowledge concerning shiftwork ca. 1990 (Scott, 1990). The papers in this book that are mentioned later in this bibliography include:
 - Shiftworker performance (Monk, 1990)
 - Sleep patterns of shiftworkers (Tepas & Carvalhais, 1990)
 - Health effects of sleep deprivation (Naitoh, Kelly, & Englund, 1990)
 - Shiftwork: Effects on sleep and health with recommendations for medical surveillance and screening (Scott & LaDou, 1990)
 - Psychiatric aspects of shiftwork (Cole, Loving, & Kripke, 1990)
 - Shiftwork effects on social and family life (Colligan & Rosa, 1990)
 - Circadian rhythm desynchronization, jet lag, shift lag, and coping strategies (Comperatore & Krueger, 1990)
 - Shiftwork and safety in aviation (Price & Holley, 1990)
 - Shiftwork as related to stress claims under workers' compensation statutes (Kennedy, 1990)
 - Intervention factors for promoting adjustment to nightwork and shiftwork (Rosa et al., 1990)
 - Shiftwork in developing countries: current issues and trends (Ong & Kogi, 1990)
 - Shiftwork in Singapore (Chan & Gan, 1993).
 - In *The Twenty-Four-Hour Society*, the author "brings together the latest scientific findings and presents a wide array of management tools and technologies that allow you to monitor alertness and performance impairment. He shows how to rethink work schedules, manage information flow and improve working environments" (Moore-Ede, 1993).
 - *The 24-Hour Business* "explains that round-the-clock business hours are no longer just for manufacturing, but can raise productivity and lower costs in a wide range of industries: retail, hospitality, transportation, insurance, banking, and many others" without squeezing employees dry (Coleman, 1995).
 - Maintaining safety and high performance on shiftwork (Monk, Folkard, & Wedderburn, 1996). A review that "discusses the situations in which shiftworker performance is critical, the types of problem that can develop and the reasons why shiftworker performance can be impaired."
 - The Human Factors Aspects of Shiftwork (Dekker, Tepas, & Colligan, 1996).
 - *Shiftwork: Basic Concern for Commanders, Supervisors and Flight Surgeons*, from the Air Force's Armstrong Laboratory (Anonymous, 1996).
 - *Sleep Secrets for Shift Workers & People with Off-Beat Schedules* addresses "the unique problems shift workers face-helps people improve the quality of their sleep so they can lead happier, healthier, more productive lives" (Morgan, 1996).
 - *Shiftworker's Handbook: A Personal Health & Lifestyle Guide for Shiftwork Professionals*

(Klein, 1997), also published in an earlier version as *The Railroader's Handbook* by Union Pacific in 1990.

- *Plain Language about Shiftwork* (Rosa & Colligan, 1997). “This document gives basic facts about shiftwork and talks about ways to make shiftwork life easier.”
- *Shiftwork Safety and Performance* (Westfall-Lake & McBride, 1997), is a good manual for managers and trainers, introducing scheduling strategies to improve alertness, enhance the quality of time away from work, and assist crew communications.
- *The Practical Guide to Managing 24-Hour Operations* is a “guide for managers and supervisors” (Dawson & Moore-Ede, 1998). It includes 14 sections: Corporate Culture; Management Development; Supervisor Responsibility; Shiftworker Lifestyle Training; Shift Scheduling; Overtime Management; Health Care & Wellness Management; Driving Safety; Sleep Management; Family & Social Support; Shiftworker Support; Work Design; The Workplace Environment; and Measurement of Alertness; and a benchmark questionnaire. Plus, common shiftwork myths and the facts behind them, information about family/social effects of shiftwork, lifestyle training, management initiatives, as well as a glossary of shiftwork terminology.
- “Brain function and effects of shift work: implications for clinical neuropharmacology” (Garbarino et al., 2002). “The implications for clinical (neuro) pharmacology are relevant and, in several instances, critical. Shift work can interfere with mechanisms regulating drug kinetics in peripheral compartments and action at selective brain sites, either directly or through effects on the gastrointestinal/hormonal cycles.”
- *Chronobiology and Shift Work* (D’Ambrosio, 2003) is a collection of excellent reviews from *Occupational and Environmental Medicine*. It provides “An overview of the health consequences of shift work, including some recommendations for screening shift workers for health problem. Updates of previous reviews on these topics are included, such as the articles on shift work and aviation, shift worker performance, and quality of life. Other articles represent areas of new research, such as the adverse effects of shift work on healthcare professionals, reproductive health, cancer risk, and aging workers. The issue ends with a thoughtful overview of the health consequences of shift work.” These reviews are not discussed below:
 - Adverse effects of shiftwork in healthcare professionals by Samir Patel and Edward B O’Malley
 - Light at night: A novel risk factor for cancer in shift workers? by Eva S. Schernhammer and Susan E. Hankinson
 - Medical screening and surveillance of shift workers for health problems by Akshay Sood
 - Overview of the medical consequences of shift work by Susan M. Rohr, Susana G. Von Essen, and Lynn A. Farr
 - Quality of life of shift workers by Carolyn M. D’Ambrosio
 - Shift work and adverse reproductive outcomes among men and women, by Linda M. Frazier and David A. Grainger
 - Shift work and aging: Roles of sleep and circadian rhythms by Jeanne F. Duffy
 - Shift work and aviation safety by Daniel C. Holley, Balasasikumar Sundaram, and

David K. Wood

- Shift worker performance by Timothy H. Monk and Julie Carrier
- Ergonomic Risks, Myths, and Solutions for Extended Hours Operations (Kerin & Kerin, 2004). “This study combines third party scientific research with data and experience collected by Circadian in 20 years of consulting, to introduce the ergonomist to the extended hour workplace, the special challenges, the ergonomics of shift scheduling, and the potential solutions for extended hours operations.”
- *Air Force Shift Worker Fatigue Survey* (Miller, Fisher, & Cardenas, 2005), an Internet-based survey of 9,242 respondents from 2003-2004 that examined the impact of shiftworker fatigue on ground mishaps and operational errors in the United States Air Force. Also, a follow-up survey, *Fatigue in military aviation shift workers: Survey results for selected occupational groups* (Tvaryanas & Thompson, 2006).
- *Shiftwork Practices 2007* (Circadian Technologies, 2008), a large-scale survey of practices in the United States. This survey is conducted every year (see www.circadian.com). The 2007 report includes data from 400 facilities and 290,000 shiftworkers.
- Round the Clock Systems of Portland, Maine, maintains a brief, annotated bibliography concerning shiftwork at www.roundtheclocksystems.com.

B. SCHEDULE STRUCTURE

These references deal more specifically with the components of a shiftwork schedule. For regular, cyclic schedules, these components include the:

- Shiftwork system
- Shiftwork plan (*rota*)
- Number of crews
- Employment ratio
- Shift rotation
- Shift length
- Shift alignment with the weekend
- Daily shift start times

One must also consider shift overlap and shift differentials. All of these components were discussed at length in an Air Force Research Laboratory report that mined many decades of shiftwork research to produce an applied design guide for regular, cyclic schedules (Miller, 2006).

Knauth et al. examined shift system goals of 8-hour work days and 104 days off per year in tabular format as functions of possible shift systems (Knauth, Rohmert, & Rutenfranz, 1979a). They showed that the 40-hour work week is cumbersome and limiting when one tries to create a shiftwork plan, and that the 42-hour work week allows even distributions of work time across workers on all shifts. The latter is true because the week length, 168 hours, is factorable by 42 hours. These investigators showed the logical, mathematical usefulness of the 42-hour work week in shift work schedules (Knauth et al., 1979a; Knauth & Rutenfranz, 1976). They also supported two useful measures

for determining the acceptability of a shift system: the average number of hours worked per day (or work load) and the number of days free per year. The importance of how one represents a *rota* was discussed by Gärtner and Wahl (1998). Knauth et al. (1983) analyzed 120 police shift *rotas* for shift cycles, duration of shifts, start and end times of shifts, the maximal number of consecutive night shifts, and the frequency of different kinds of free weekends.

Interactions between shift length (8 or 12 hours) and shift start time (0600 or 0700) were assessed by Tucker, Smith, Macdonald, and Folkard (1998a). They noted that “Night sleeps between consecutive shifts that started at 6 a.m. were shorter and more disrupted than those starting at 7 a.m. Day sleeps following night shifts that finished at 6 a.m. were longer and less disrupted than those finishing at 7 a.m. Early starts were associated with poorer psychological and physical health.” They also noted that “Although several measures favored 12-hr shifts, physical health indicators appeared to favor 8-hr systems, especially in combination with late changeovers.” Elsewhere, they reported that “Effects on alertness can be explained in terms of differences in elapsed time on duty, sleep duration, sleep disruption, and chronic fatigue” (Tucker, Smith, Macdonald, & Folkard, 1998b).

Tucker et al. also examined the effects of different numbers of days off within a *rota* (Tucker, Smith, Macdonald, & Folkard, 1999). They found that “Systems which incorporated rest days between the day and night shifts were associated with slightly higher levels of on shift alertness, slightly lower levels of chronic fatigue, along with longer sleep durations when working night shifts and between rest days.” Dula, Dula, Hamrick, and Wood found that “Working a series of 5 night shifts results in a substantial decline in cognitive performance in physicians working in the [Emergency Department]” (2001).

1. Shift Length

Spurgeon, Harrington, and Cooper (1997) provided a discussion of working more than 48 hours per week, concluding that “there is currently sufficient evidence to raise concerns about the risks to health and safety of long working hours.”

In theory, shift length may be any amount of time up through 24 hours. In practice, only several factors of 24 hours (4, 6, 8, or 12 hours) are useful. If one uses values that are not factors of 24 hours, then the time that an individual reports for work on the same shift is unpredictable: it differs from day to day. Shift lengths of 4 and 6 hours are used primarily in maritime watchstanding while underway. A discussion of watchstanding systems may be found in Miller, 2006, pp. 83-86.

The most-debated issue concerning shift length these days concerns the use of 12-hour shifts instead of 8-hour shifts. Shiftworkers are quick to notice that, due to the work compression afforded by 12-hour shifts, they may have longer continuous periods of time off when working 12-hour shifts than when working 8-hour shifts (Miller, 2006). These longer time-off periods are viewed as being of high value, so shiftworkers often prefer 12-hour shifts to 8-hour shifts. However, it is well-known that accident risk increases disproportionately toward the end of long shifts. The best meta-analysis of industrial data showed that relative “risk increased in an approximately exponential fashion with time on shift such that in the twelfth hour it was more than double that during the first 8 h” (Folkard & Tucker, 2003). On the other hand, the work compression available with 12-hour shifts allows for more consecutive days off within a *rota*, which, in turn, provides better quality time off and better recovery from night work (Miller, 2006).

The author of an extensive review of this issue (Lewis, 1985) concluded that 12-hour shifts were not appropriate for continuous operations. Lewis thus recommended a number of administrative controls for the implementation of 12-hour shifts. Kelly and Schneider (1982) noted a differentiating factor for the selection of the 12-hour rather than the 8-hour shift length: public risk. If the shift workers are responsible for the safe operation of a dangerous facility, such as a nuclear power generating station, 12-hour shifts may not be acceptable. For the manager or shiftworker, the best evaluation of the 12-hour shift length, compared to the 8-hour length, was provided by Moore-Ede, Davis, and Sirois, 2008. The following, additional journal articles and technical reports all addressed the issue of shift length. Comments are extracted from abstracts and sorted by results.

Results that favored the use of 12-hour shifts:

- Peacock et al. found no difference in physiological or subjective measures for police switching from 8- to 12-hour shifts. The police accepted the 12-hour shift length. However, their 8-hour plan called for backward rotation, known to be more stressful for most people than forward rotation. Perhaps these 8- and 12-hour shift plans were both stressful (Peacock, Glube, Miller, & Clune, 1983).
- Gould found that “the advantages outweigh the disadvantages. The primary advantages are greater job satisfaction, fewer errors, and the better communications inherent in two shift turnovers versus three. Several companies that implemented the 12-hour shift found an increase in employee morale, no adverse effect on worker health, and no decline in safety. They experienced greater productivity, fewer operator errors, and better communication” (Gould, 1989).
- “[T]he introduction of a 12-hour shift system did not result in increased accidents” (Laundry & Lees, 1991).
- “The results indicate no serious health problems among workers on 12 h shift for over a year” (Chan, Gan, & Yeo, 1993).
- For a group of mine workers, “Results indicate nearly unanimous acceptance and improved sleep quality associated with the new schedule” (Duchon, Keran, & Smith, 1994).
- The change in working hours from 8- to 12-hour shifts “produced improvements in health, particularly in psychological health and in reduced feelings of tiredness throughout the work period,” and “was at no cost to feelings of job satisfaction or the worker's perceptions of any particular aspects of the work environment, or to measures of productivity” for computer operators (Williamson, Gower, & Clarke, 1994).
- “12-hour shifts do not cause increased sleepiness or impaired performance or disturbed sleep” (Axelsson, Kecklund, Akerstedt, & Lowden, 1998).
- “[T]he pattern of 12-hour shifts [DDNN], which was democratically implemented, was preferred by the nursing staff and did not diminish their well-being and work performance” (Campolo, Pugh, Thompson, & Wallace, 1998).
- “The change from 8-hour to 12-hour shifts was positive in most respects...” (Lowden, Kecklund, Axelsson, & Akerstedt, 1998).
- “The bulk of the evidence suggests few differences between eight and 12 hour shifts in the way they affect people” (Smith, Folkard, Tucker, & Macdonald, 1998).

- (Bloodworth, Lea, Lane, & Ginn, 2001): “demonstrat[ed] the benefits a change in shift pattern to 12-hour shifts can have for patients and staff in a ward environment.”
- “Twelve-hour shifts in critical care areas are suitable shift patterns for nurses, patients and management, provided that they are fundamentally well-managed” (McGettrick & O'Neill, 2006).
- “[T]he 12-hour roster was a positive recruitment ... strategy” (Dwyer, Jamieson, Moxham, Austen, & Smith, 2007).
- “Most participants believed 12-hour shifts should continue” (Richardson, Turnock, Harris, Finley, & Carson, 2007).

Results that did not show clear differences between 8- and 12-hour shifts:

- Nuclear power plant “operators and maintainers ... had attitude and preference differences related to ... 12 hour shift schedules...” (Smiley & Moray, 1989).
- “[N]o significant differences in 8-hour and 12-hour shifts on and off-duty accident rates or day and night shift accident rates. Reported levels of fatigue were significantly greater when 12-hour shifts were used” (Campbell, 1998).
- “The nurses working in a 2-shift system were more tired after work, but they could spend more time on leisure activities and do housework” (Makowiec-Dabrowska, Krawczyk-Adamus, Sprusińska, & Jóźwiak, 2000).
- “[S]ignificant differences [between] performance of older and younger subjects during a simulated 12 hour shift rotation” (Reid & Dawson, 2001).
- “[I]nsufficient evidence to support definitive conclusions” (Driscoll, Grunstein, & Rogers, 2007).
- “[R]equests for extending working hours should thus be handled with care” (Raediker, Janssen, Schomann, & Nachreiner, 2006).
- “[C]aution is advised when considering the introduction of extended work shifts, particularly where public safety is at stake” (Knauth, 2007).
- “[A]ny schedule changes to reduce work-related fatigue need to consider circadian performance variation and the potential transfer of workload and fatigue risk between trainees and specialists” (Gander, Millar, Webster, & Merry, 2008).

Results that did not favor the use of 12-hour shifts:

- Gardner and Dagnall (1977) reported increased absences due to sickness for process workers in an oil refining and petrochemicals plant as a result of a switch from 8- to 12-hour shifts.
- Mets (1986) reported increased injury rates for workers in the heavy and light press shops of an automobile manufacturing plant as a result of a switch from 9- to 12-hour shifts.
- “12-hour shifts have a moderate impact on productivity measurements” (Collette, 1999).
- “[R]esidents generally tolerate shiftwork well and prefer 8-hour or 10-hour shift lengths compared with 12-hour shift lengths” (Steele, Ma, Watson, & Thomas, 2000).
- “[T]hese findings of decreased alertness during the terminal hours of the [12-hour] night shift are of concern, since they suggest risk of compromised patient care” (Borges &

Fischer, 2003).

- “Working at least 12 hours per day was associated with a 37% increased hazard rate...” (Dembe, Erickson, Delbos, & Banks, 2005).
- “[P]oorer sleep after and significantly decreased alertness during night work” with 12-hour shifts (Fischer, de Moreno, Notarnicola da Silva Borges, & Louzada, 2000).
- “[C]hanging from 8 to 12 hour shifts affected worker well being and morale” (Overland, 1997).
- “[T]here is evidence that extended workdays (9-12 h) should be avoided as much as possible” (Poissonnet & Véron, 2000).
- “Night shift workers who worked for 12 h or more a day were exposed to a risk of severe sleepiness that was 7.5 times greater than day shift workers who worked less than 11 h” (Son, Kong, Koh, Kim, & Härmä, 2008).

Several abstracts did not describe results (Baker, 1995; Baker & Morisseau, 1992; Frakes & Kelly, 2004).

Kecklund, Ekstedt, Akerstedt, Dahlgren, & Samuelson (2001) examined double-shifting (16 hours of work) in construction and observed that “The short rest time (8.5 hours) between days caused insufficient sleep and approximately 5.5 hours of sleep was obtained between double shifts. Questionnaire data showed that complaints of insufficient sleep, exhaustion on awakening and pain symptoms increased across the year”. They concluded that “a shift system involving double shifts has a negative effect on fatigue, recovery and health-related well-being.”

2. Shift Rotation

On fixed shifts, the worker always works the same shift; for example, permanent days or permanent nights. Most fixed-shift workers tend to become dissatisfied with fixed shifts and wish to “graduate” to day shifts. Besides obvious inequities for workers between fixed day and night shifts, fixed night-shift workers usually do not keep their day-sleep, night-work schedule on days off. Thus, fixed shift schedules assume much of the nature of poorly-scheduled rotating shifts.

Though there are usually some major problems with fixed shifts, there are workers who prefer night work to day work and function quite well at night. If an operation requires only a skeleton crew for night operations, then a fixed night shift may be appropriate. Other workers may be assigned to permanent day shifts, to permanent day and swing shifts or to alternating day and swing shifts. Workers on day and swing shifts usually get adequate nocturnal sleep.

Many 24/7 operations are supported by regular, cyclically-rotating shiftwork, in which the worker changes (rotates, as the hands of a clock rotate around the clock face) from one shift to another at some specified interval, be it “fast” or “slow.” A fast rotation is one in which the workers move to a new shift start time once every few days or less. A slow rotation is one in which they change shifts every few weeks or less often. Weekly changes are the least desirable in terms of minimizing physiological disruptions and should be avoided.

The rotation pattern, too, has been a controversial issue. A good example of the nature of the controversy was provided by the position taken by the famous fatigue and vigilance investigator, Wilkinson, and the subsequent rejoinders by equally famous and qualified scientists Wedderburn and Folkard, all three from the United Kingdom (Folkard, 1992; Wedderburn, 1992; Wilkinson, 1992).

Wilkinson's (1992) review of the literature led him to conclude "that permanent (zero rotation), fixed-night systems are superior on most counts, and should be implemented for night work, leaving the option of rapid rotation to cover the two (morning and afternoon) day shifts." This is certainly an option that is viable if one can find reliable, qualified personnel who are willing to work a permanent night shift. Wedderburn (1992) responded to Wilkinson, pointing out some personnel problems with permanent night workers and noting that "Studies of industrial production show very slight differences between output on different shifts, unlike laboratory studies..." Folkard (1992) also responded, saying that Wilkinson had "(i) overestimated the problems associated with rapidly-rotating shift systems; and (ii) underestimated the problems that might be encountered in trying to implement effective permanent night shift systems." Folkard (1992) went on to state a position that remains relevant:

[T]he evidence does not allow a general choice to be made between the use of either permanent night shifts or rapidly rotating, delaying, shift system. Rather the choice between them would appear to depend on the relative importance attached to safety and social problems in any given workplace.

Bambra, Whitehead, Sowden, Akers, and Petticrew (2008) published a meta-analysis indicating that "three types [of intervention] were found to have beneficial effects on health and work-life balance: (1) switching from slow to fast rotation, (2) changing from backward to forward rotation, and (3) self-scheduling of shifts."

a. Comparison of Rotating to Permanent Shifts

"Even after 21 consecutive night shifts we failed to find complete inversion of the daily course of body temperature. In view of these test results rapidly rotating shift systems would seem to be advisable" (Knauth & Rutenfranz, 1976).

- "Significant differences between the groups only emerged in the amount of night sleep before the shift" (Alward & Monk, 1990).
- "...non-rotational workers enjoyed more frequent and longer naps and had less disturbances in their sleep patterns than rotational workers" (Shah, 1990).
- "In comparison to nurses who worked only day/evening shifts, rotators had more sleep/wake cycle disruption and nodded off more at work. Rotators had twice the odds of nodding off while driving to or from work and twice the odds of a reported accident or error related to sleepiness" (Gold et al., 1992).
- "[Rotating] workers were more frequently morning types whereas the [permanent night shift] workers were more frequently evening types" (Petru, Wittman, Nowak, Birkholz, & Angerer, 2005).
- "[I]n normal environments, permanent night-shift systems are unlikely to result in sufficient circadian adjustment in most individuals to benefit health and safety" (Folkard, 2008).

b. Comparison of Forward to Backward Rotation

- "The backward rotation of shifts was unfavourable because of the short time off between the last afternoon shift and the first morning shift. Furthermore, short

- nightwork periods and a start of the morning shift which is not too early seem to be preferable” (Knauth, Kiesswetter, Ottman, Karvonen, & Rutenfranz, 1983).
- “The present results provide support to the claim that rotating shiftworkers can better adapt to clockwise than counter-clockwise rotations” (Lavie, Tzischinsky, Epstein, & Zomer, 1992).
 - Barton *et al.* found that one “change from a delaying to an advancing system resulted in an increase in sleep difficulties between successive afternoon shifts, but a decrease in social disruption” (Barton, Folkard, Smith, & Poole, 1994).
 - “There is a lack of reliable data on the effects of permanent vs. rotating-shift systems on alertness, performance and accidents. This is also true for the comparison of forward (delaying) and backward (advancing) rotating-shift systems, although the former would seem to be associated with fewer problems” (Knauth, 1995a).
 - “Few effects were found of direction of rotation on chronic measures of health and wellbeing ... However, advancing continuous systems seemed to be associated with marginally steeper declines in alertness across the shift ... They were also associated with shorter sleeps between morning shifts ... but longer sleeps between afternoons ...” (Tucker, Smith, MacDonald, & Folkard, 2000).
 - “...a fast forward rotating shift schedule is more suitable for older workers than a slower backward rotating system” (Hakola & M Härmä, 2001).
 - Nesthus *et al.* (2001) compared the backward-rotating, unique, FAA air traffic controller schedule to a forward, rapid rotation and noted that, for the circadian rhythm of body temperature, “An attenuation of amplitude and a delay in the acrophase was the found for the counter-clockwise condition.”
 - “A backward rotation schedule was prospectively related to an increased need for recovery ... and poor general health ... as compared with a forward rotation schedule. ... Furthermore, a forward rotation schedule was prospectively related to less work-family conflict and better sleep quality over the 32 months of follow-up. Finally, high levels of fatigue, need for recovery, poor sleep quality, poor general health, insufficient leisure time, and work-family conflict at first measurement were associated with an increased risk of leaving shiftwork during the follow-up” (van Amelsvoort, Jansen, Swaen, van den Brandt, & Kant, 2004).
 - “[T]he very rapidly forward rotating shift system had positive effects on the sleep, alertness and well-being of especially the older shift workers” (Härmä *et al.*, 2006).
 - “No effect of rotation system on [simulated] driving performance could be shown. The subjective sleepiness scores were significantly higher in the slow-backward rotating group than in the fast-forward rotating group” (De Valck, Quanten, Berckmans, & Cluydts, 2007).
 - A systematic review found that “there is insufficient evidence to support definitive conclusions regarding any of these factors. However, the analysis provides support for the use of forward rotating shift systems in preference to backward rotating shift systems, at least as far as 8-hour shifts are concerned” (Driscoll *et al.*, 2007).
 - For air traffic controllers, apparently in New Zealand, “a 4-d counterclockwise, rapidly

rotating schedule results in a progressive reduction in sleep and consequently the rapid accumulation of a sleep debt” (Signal & Gander, 2007).

- “The rotation direction interacted with the shift significantly and as a result higher cortisol values during the morning and night shifts in the backward rotating group were found as well as worse quality of sleep. Higher salivary cortisol during morning and night shifts and worse quality of sleep in engineers working very fast backward-rotating shifts may be an indication for insufficient recovery” (Vangelova, 2008a, 2008b, 2008c).

For backward rotation schemes used by air traffic controllers, see the section, Occupational Risk and Safety—Aviation—Air Traffic Control, below.

c. Frequency of Rotation

- “Shift times systematically affected sleep patterns. Within [rapidly rotating] shifts, Ss slept as late as possible prior to the morning shift, went to bed shortly after the night shift, and slept approximately midway between shifts on the afternoon shift. In transitioning to a new shift, the new shift time tended to determine sleep time. Sleep was significantly longer in transitions between shifts. Sleep structure was not markedly changed” (Webb & Agnew, 1978).
- “In the laboratory experiments with fixed sleep durations, no separate effects on sleep quality could be established for different shift systems” (Knauth & Rutenfranz, 1980).
- “Rapidly rotated shift systems had more advantages referring to the total amount of night sleep than weekly rotated shift systems” (Knauth et al., 1983).
- “[T]he slower the shift system rotated [in the laboratory] and the later the individual circadian phase position was, the more subjects were able to follow the different shift systems” (Moog & Hildebrandt, 1987).
- “The numerical results [of modeling] supported Czeisler’s findings (1982), indicating the best shift schedules adopt a slow, forward-shifting rotation pattern, rotate shifts after 2-week periods and allow an average of 2 days off per week” (Kostreva, McNelis, & Clemens, 2002).

d. Flexible Hours

This section of the report does not deal with continuous, cyclic shift rotations. Instead, it deals with compressed work schedules and other schedules with “irregular” timing; i.e., work that does not occur five days per week and during daylight hours.

The U.S. Congressional Office of Technology (OTA) reported increasing use of the compressed work week, usually 40 hours in fewer than 5 work days. Often, the compressed work week is four 10-hour days (OTA, 1991). The San Antonio Air Logistics Center, Human Resources Center, (SA-ALC/HRC) at Kelly AFB, TX, requested an evaluation of worker attitudes during a trial transition from an 8-hour per day, 5-day work week to a 10-hour per day, 4-day work week; a Compressed Work Schedule (CWS). Several of my former colleagues reported results at 30 days (French, Oakley, Fischer, Dowd, & Storm, 1992), six months (Dowd, French, Oakley, Fischer, & Storm, 1993), and one year into the trial (Dowd, Oakley, French, Fischer, & Storm, 1994). Although the majority of the workers favored the CWS consistently, certain characteristics emerged for those who did not. Certain directorates,

older employees, those over 30 years in Federal service, higher wage grade employees, and night shift workers were groups that expressed less preference for the CWS, compared to the previous 5-day work week. However, generally, there were quality of life improvements under the CWS both at home and at work.

Many years later, Hänecke, Grzech-Sukalo, and Jaeger (2001) presented three cases that represented “a diversity of variable or flexible working time systems according to different branches [within a company] and different anticipated aims to reach with flexibility. For companies flexibility should improve or at least consolidate their economic situation, and for employees flexibility should result in a beneficial effect on health, family and social life”. Kandolin, Härmä, and Toivanen (2001) examined flexible overtime and irregular work hours in Finland and concluded that “A better balance between company-controlled and individual flexibility would ... improve the well-being of employees.” Tucker, Gaertner, and Mason (2001) helped a company implement a new flexible work hours system and concluded that “the key elements in the process of designing [flexible] systems are centred around issues of trust and communication; the involvement of a broad range of interested parties, through a process of carefully managed group facilitation; and the need for adequate technical [i.e., software] support....”

Subsequently, representatives from the European Union met to examine critically the implementation of flexible work time in European countries (Costa et al., 2004). They concluded that “there is a large-scale intervention ongoing in our society with almost completely unknown and uncontrolled effects. Consequently, there is a strong need for systematic research and well-controlled actions in order to examine in detail what flexible working hours are considered, what and where are their positive effects, in particular, as concerns autonomy, and what regulation seem most reasonable” (Costa et al., 2004). Janssen and Nachreiner (2004) acquired data about flexible work hours from two large samples of workers and concluded that “high variability of working hours is associated with increased impairments in health and well-being and this is especially true if this variability is company controlled.”

Eriksen and Kecklund (2007) compared “a flexible shift system (based on self-determined work hours)” to “a rapidly rotating shift system, with frequently occurring quick returns.” The sample “included 533 randomly selected police officers, of which 26% were females. ... The results showed that the flexible shift system group did not differ with respect to sleep/wake complaints and subjective health. However, the flexible shift group obtained more sleep in connection with the shifts, probably because of longer rest time between shifts. Thus, they worked less quick returns and long work shifts. The association between work hour characteristics and sleep/wake complaints was weak in the flexible shift group. Instead, sleep/wake problems were mainly associated with the attitude to work hours.”

C. CIRCADIAN RHYTHM DISRUPTION

There are normal, inherent, unavoidable, 24-hour rhythms in human cognitive and physical performance. Most of these circadian rhythms oscillate between a high point late in the day to a low point in the pre-dawn hours with a peak-to-trough amplitude of about 5 to 10% of their average value. Human circadian rhythms are slightly longer than one cycle per day, but are normally slaved, or entrained, to exactly one cycle per day by external time cues (*Zeitgebers*), especially the daylight-darkness cycle.

“Shift lag” is the feeling of *malaise* and fatigue that accompanies a change from day work to night work and *vice versa*. Shift lag occurs during the period of attempted re-synchronization of circadian rhythms to new external time cues. Compared to jet lag, the attempt to re-synchronize to a night work and day sleep schedule occurs more slowly and is much less successful because the main time cue, the daylight-darkness cycle, tends to inhibit re-synchronization.

A very large proportion of research and writing about shiftwork has focused on the disruptive effects of irregular work schedules and night work on human circadian rhythms, and the known and suspected sequelae of that disruption. Excellent discussions of the circadian disruptions caused by shiftwork were provided early on (Aschoff, Hoffmann, Pohl, & Wever, 1975; Hildebrandt, 1976; Naitoh, 1980; Reinberg, Vieux, Ghata, Chaumont, & Laporte, 1978; Wever, 1980).

A set of work-rest investigations by Colquhoun, Blake, Edwards, and Hockey from 1968-69 described the nature of circadian variations in body temperature and performance (Colquhoun, 1980; Colquhoun, Paine, & Fort, 1978; Hockey & Colquhoun, 1972). They compared rotating and fixed 4-hour work periods, 8-hour fixed work periods, and 12-hour fixed work periods across 12 days. The rotating 4-hour system was composed of six 4-hour work periods (00-0400, 08-1200, 20-0000, 04-0800, 16-2000, and 1230-1630) across a period of 72 hours (12 male participants). These rotating work periods were compared in terms of physiology and performance to fixed work periods that occurred at 00-0400 and 1230-1630 each 24 hours (16 male participants).

Circadian variations in body temperature and most performance measures correlated positively with each other. The exception was short-term memory. Various tests of short-term memory displayed relatively flat patterns or even an inverted circadian pattern compared to temperature. Vigilance performance for the rotating 4-hour work condition correlated positively with body temperature, with a 13% peak-to-trough range in signal detection proportion and an 8% range in response latency, with no significant variability in false alarms. This pattern suggested that perceptual efficiency improved with higher body temperatures, as opposed to just a lowering of the decision criterion. Body temperature and vigilance performance in the fixed work system phase shifted together across the first five days of the 12-day experiment, indicating an adjustment of the participants' circadian rhythms to the fixed work schedule. They concluded the 12 days with an approximate range of 16% peak-to-trough range in signal detection proportion and 8% in response latency, with no significant variability in false alarms.

While the linked circadian rhythms of body temperature and vigilance performance measures continued unabated for rotating shiftwork in the Colquhoun studies (Colquhoun, 1980; Colquhoun, Paine, & Fort, 1978; Hockey & Colquhoun, 1972), the fixed 4-hour work schedule caused an initial flattening and a phase delay (5 h across 5 d) in body temperature and vigilance performance. This finding argued favorably for the usefulness of a rotating work schedule rather than a fixed work schedule if one wishes to avoid the painful period of adjustment to a new, fixed schedule.

Seeking normative values for their previous work, Colquhoun et al. (1978, 1979) looked back upon their hourly temperature readings from 59 young, healthy Navy personnel who were not standing watch periods and were sleeping normally at night. They fitted the group mean data with 24- and 12-hour sine and cosine curves (harmonic analysis), explaining 99% of the variance in the group mean data with the fundamental (24-hour period) and first harmonic (12-hour period). The resulting, complex curve was composed of a 24-h-period waveform with acrophase at 17:00 and peak-to-peak amplitude 1.06 deg F. The acrophase of the combined curve occurred at 20:00 and the peak-to-peak

amplitude was 1.20 deg F. The minima of the fundamental and combined curves occurred at 05:00 and 04:00, respectively. This curve was taken to represent the normal, underlying pattern of circadian-plus-circasemidian variation in body temperature. In fact, the publication of this information was a benchmark, initiating widespread consideration by circadian rhythm investigators of the 12-hour circasemidian rhythm in body temperature.

In their earlier studies, Colquhoun et al. (1978, 1979) had noted that circadian rhythm flattening had not occurred until the last of four contiguous 72-hour cycles used in those investigations. Now, they had the opportunity to collect temperature data (at 3-hour intervals) from eight submarine sonarmen during a 48-day cruise. The sonarmen worked a “traditional” 1-in-3, 4-hour work system that repeated every 72 hours as follows from 00:00 of day 1: 4 on, 4 off, 4 on, 8 off, 4 on, 12 off, 4 on, 12 off, 4 on, 8 off, 4 on, 4 off. In this system, an individual works three 4-hour periods on day 1, one on day 2 and two on day 3. There were two each 4-, 8- and 12-hour time-off periods. This schedule allowed two contiguous 8-hour sleep periods each 3 days.

Harmonic analysis (fixed 24- and 12-h-period cosine fits) was attempted for each of 16 contiguous, 72-hour cycles (16 cycles x 3 days/cycle = 48 days) for the 8 sonarmen (16 cycles x 8 sonarmen = 128 data samples). Good fits for the 24-hour period, fundamental harmonic were achieved in only 68% of these 128 samples. Thus, circadian rhythm disturbances were certainly present. Amplitude declined slightly in the first several cycles, and then more sharply across the 48-day period. Acrophase drifted slightly later in the first several cycles, and then more sharply, also. However, these trends may have been caused by the fact that the cosine wave fit method became less and less effective across the 48 days.

When the circasemidian curve was added to the fundamental, circadian curve, good curve fits were achieved in 88% of the samples. Amplitude and acrophase for the combined curve remained fairly stable for several cycles, and then decreased and increased, respectively, more sharply across the 48-day period. Again, greater inter-subject inconsistencies, as measured by the combined-curve fit, became greater and greater across the 48 days. Probably, circadian rhythm disruptions worsened gradually across the 48 days. Certainly, the sleeping patterns of the sonarmen changed across the 48 days, with more and more sleep periods being taken in the 08:00-00:00 (submarine “day”) period and fewer in the 00:00-08:00 (submarine “night”) period.

Turek (1986) noted that “Circadian rhythms may be disrupted when shift workers rotate from one work schedule to another.” “It has been suggested that in order to minimize the time needed to readjust circadian rhythms to a new work schedule the work time of shift workers should be rotated in a delaying rather than an advancing direction. However, delaying or advancing the work time does not imply that the sleep-wake cycle is also shifted in a similar manner. Indeed, after a complete rotation between the day, evening, and night shifts the sleep time will be advanced once, delayed once, and not shifted once, regardless of whether the workers are on a delaying or an advancing work rotation schedule. Thus circadian rhythms are likely to be perturbed in a similar manner whether the work schedule is rotated in a delaying or an advancing direction.”

Hildebrandt (1987) published an “overview” that stressed “why it is important to avoid the effect of masking and presents a model of the mechanism of circadian synchronization based on circadian changes of nonspecific responsiveness to various *Zeitgeber* qualities.” “The significance of phase responses, transitory uncoupling, frequency multiplication, and flattening of circadian functions

is considered. Even circadian adaptation undergoes a circaseptan reactive periodicity.” Moog and Hildebrandt (1989) considered the chronobiological characteristics of night and shift work, and features of the adaptive process to be expected. Then they discussed the “Demands for experimental routines to imitate these situations and the need for routines reducing masking effects,” and reviewed experiments that would meet these demands are reviewed. Practical considerations and inter-individual differences of the circadian system were taken into account.

The U.S. Congressional Office of Technology Assessment (OTA) published an excellent, landmark summary of what was known about work-related aspects of biological rhythms in 1991, before it closed in 1995 (OTA, 1991). Apparently, the same report was re-published by the University Press of the Pacific in 2005 (OTA, 2005). Much of the information in this report is still quite relevant. In preparation for this report, the OTA commissioned six reviews:

- Biological Rhythms and Human Performance (Campbell, 1989)
- Shift Work and the Worker (Monk, 1989)
- Shift Work and Nursing (Weisman, 1989)
- Military Applications of Circadian Rhythm Principles (Hull, 1990)
- Shift Work and Society. Demographics and Social Implications (Presser, 1990)
- Legal and Regulatory Issues Related to Work Schedules and Hours of Work (Mintz, 1991)

These reviews are incorporated into the parent document (OTA, 1991, 2005). Härmä, Waterhouse, Minors, and Knauth (1994) investigated the phenomenon of “masking” on the estimation of circadian adjustment, concluding that “Masking effects on body temperature should be taken into account before any definite conclusions can be drawn about the relation between individual factors and the adjustment of the circadian rhythm of body temperature.” Hildebrandt (1987) echoed this concern about the effects of masking.

While not specific to shiftwork, important information was provided by Mistlberger and Skene (2004) in their critical assessment of “the evidence for social influences on mammalian circadian rhythms, and possible mechanisms of action.” They concluded that “The best evidence for social entrainment in humans is from a few totally blind subjects who synchronize to the 24 h day, or to near-24 h sleep-wake schedules under laboratory conditions.” They noted that additional research is warranted. Aschoff et al. (1971) had previously demonstrated that “Social cues are sufficient to entrain human circadian rhythms.”

Excellent, recent reviews have been provided by Folkard (2008), who concluded that “in normal environments, permanent night-shift systems are unlikely to result in sufficient circadian adjustment in most individuals to benefit health and safety”; by Lewy (2007), who discussed recent advances in melatonin and light therapies for circadian rhythm disturbances; and by Reinberg, Ashkenazi, and Smolensky (2007), who describe and define internal desynchronization.

Gupta, Pati, and Levi (2007) found that “rhythms of subjective fatigue and subjective drowsiness are governed neither by oral temperature oscillator nor by the sleep/wake cycle oscillator” and that the “shift rotation pattern chiefly modulates the circadian time structure of shift workers....”

Several investigations have focused mainly on the circadian aspects of human physiology as related to shiftwork. These include:

- Heart rate (Colquhoun, 1988)

- Oral temperature (Knauth, Emde, Rutenfranz, Keiswetter, & Smith, 1981; Nesthus et al., 2001)
- Oral temperature, grip strength of both hands, peak expiratory flow and heart rate (Reinberg et al., 1988)
- Heart rate and oral temperature (Sen & Kar, 1978)

There are several other, more generic articles available that discuss and review varying aspects of interactions between circadian rhythms and shiftwork (Campbell, 1989; Folkard, Minors, & Waterhouse, 1985; Hildebrandt, 1987; Monk, 1989, 1990; Moog & Hildebrandt, 1987; Richardson & Tate, 2000; Turek, 1986; West, 2001).

1. Circadian Sleep Disruption

Morgenthaler et al. (2007) is an excellent, current reference for understanding interactions between circadian rhythm disruption and sleep, and how one may treat circadian-disruption-induced sleep disturbances. Additional resources on this subject include (Åkerstedt, 1998; Akerstedt, Kecklund, & Knutsson, 1991; Czeisler, Moore-Ede, & RH Coleman, 1982; Duffy, Dijk, Klerman, & Czeisler, 1998; Gooley, 2008; Kiesswetter, 1993; Knauth et al., 1980; Mauvieux, Gouthière, Sesboüe, & Davenne, 2003; Santhi, Duffy, Horowitz, & Czeisler, 2005; Santhi, Horowitz, Duffy, & Czeisler, 2007; Thorne, Hampton, Morgan, Skene, & Arendt, 2008; Van Reeth, 1998; Van Reeth & Mennuni, 2002; Vidacek, Radošević-Vidacek, Kaliterna, & Prizmić, 1993).

Also, see the subsection on Shift Work Sleep Disorder, below.

D. OCCUPATIONAL RISK AND SAFETY

Two collections of information about occupational risk and safety in shiftwork were provided by Haider (1986) and then Colquhoun (1996);

Costa (2001) discussed the “24-hour society.” The author asked, “[W]hat kind of 24-hour society do we need? At what costs? Are they acceptable/sustainable?” “What are the advantages and disadvantages for the individual, the companies, and the society? What is the cost/benefit ratio in terms of physical health; psychological well-being, family and social life? The research on irregular working hours and health shows us what can be the negative consequences of non-human-centered working times organisations. Coping properly with this process means avoiding a passive acceptance of it with consequent maladjustments at both individual and social level, but adopting effective preventive and compensative strategies aimed at building a more sustainable society, at acceptable costs and with the highest possible benefits.”

Folkard (2006; Folkard, Lombardi, & Spencer, 2006) created a spreadsheet estimator for risks of injuries and accidents during shiftwork. Much of the data used in the calculations were reported previously (Folkard & Tucker, 2003). The reference list in the technical report (Folkard, 2006) includes a number of relevant articles and reports that are not repeated here. Folkard’s technical report, spreadsheet, and user’s guide are available at <http://www.hse.gov.uk/research/rrhtm/rr446.htm>.

1. Aviation

Nicholson and Stone (1982) provided an early guide for flight medical officers. The guide addressed the relation between alertness and sleep, and the nature of sleep and circadian rhythmicity

in the settings of shiftwork, transmeridian flight and air operations. They also discussed disorders of sleep and arousal and the use of hypnotics. Sanders, Chaturvedi, and Hordinsky (1998) discussed the potential uses of melatonin in aviation operations, including air traffic controllers and maintenance workers.

a. Aeromedical

- “Air medical team members report for [12-hour night] shifts with a significant sleep debt that does not differ between crewmembers permitted on-duty rest and those with on-duty rest prohibitions. More than half of flight team members surveyed have [outside employment] and many report for flight duty within 8 hours of leaving their other job. [12-hour night] shift crewmembers are at a particularly high risk for the consequences of fatigue” (Frakes & Kelly, 2005).
- “Provided adequate daily sleep (at least 7 hours/day) is obtained, we found no difference or decline in the cognitive function of flight nurses working either a 12-hour evening or 18-hour shift during a 72-hour duty schedule” (Thomas, Hopkins, Handrahan, Walker, & Carpenter, 2006).
- Outside employment “is common for 24H medical staff and some personnel report for flight duty within eight hours of leaving an OE position. As the industry considers the impact of fatigue on operational safety, shift length, on-duty rest, and outside employment will be important considerations” (Frakes & Kelly, 2007).

b. Air Traffic Control

Luna, French, and Mitcha (1997); Luna, French, Mitcha, and Neville (1994) assessed USAF air traffic controllers working a forward 2-2-2 rapid rotation shift schedule. They found significantly more sleep, more fatigue and confusion and decreased vigor and general activity levels on the night-shift. Significantly more sleep occurred after the swing-shift than the day-shift. In a subsequent review of the literature, Luna (1997) found that civilian controllers’ “performance declines on the night-shift and that [controllers] may be falling asleep while on-duty.” For air traffic controllers, apparently in New Zealand, Signal and Gander (2007) observed that “a 4-d counterclockwise, rapidly rotating schedule results in a progressive reduction in sleep and consequently the rapid accumulation of a sleep debt.”

The Federal Aviation Administration’s Civil Aeromedical Institute (FAA CAMI) has published a number of studies on a unique, non-cyclic schedule used by civilian air traffic controllers in the United States (Boquet et al., 2002; Cruz, Della Rocco, & Hackworth, 2000; Cruz, Detwiler, Nesthus, & Boquet, 2002; Cruz, Boquet, Detwiler, & Nesthus, 2003, 2002; Della Rocco, 1999; Della Rocco & Cruz, 1995, 1996; Hackworth, Schroeder, & Bleckley, 2004; Melton, 1985; Melton & Bartanowicz, 1986; Melton et al., 1973; Nesthus et al., 2001; Nesthus, Cruz, Hackworth, & Boquet, 2006; Smith, 1973). This schedule includes one backward rotation to a night shift at the end of 5 days of work (Melton et al., 1973). Many controllers take a nap before this night shift. Nesthus et al. (2001) compared the backward-rotating, unique controller schedule to a forward, rapid rotation and noted that, for the circadian rhythm of body temperature, “An attenuation of amplitude and a delay in the acrophase was the found for the counter-clockwise [backward] condition.”

In 1999, an FAA Air Traffic Control Shiftwork Study “was conducted in response to a mandate from Congress to learn more about the shift schedules, sleep patterns, and fatigue of air traffic controllers (ATCS)” (McCloy, 2001). Data from 4,112 enroute and terminal ATCS were acquired. The reported sleep duration on days off was 8.3 hours. Sleep durations for shift start times of early morning (before 08:00), day (08:00 to 09:59), mid-day (10:00 to 12:59), and afternoon (13:00 to 19:59) were 6.5, 7.3, 7.9, and 8.0 hours, respectively. Sleep durations for shift start times before midnight (20:00 to 23:59) and after midnight (00:00 to 01:00) were 3.6 and 4.3 hours, respectively. The main health complaints were headaches (26% of respondents), chronic back pain (21%), sinusitis or tonsillitis (21%), and hemorrhoids (18%). “More than a third of the controllers reported falling asleep while driving home after a midnight shift” (McCloy, 2001).

c. Army Helicopter Operations

Comperatore et al. (1992) noted the problem of Army aviation personnel often encountering “work schedules which require the transition from daytime to nighttime duty hours without the benefit of an adaptation period” and discussed the associated challenges. Subsequently, this group examined “the effects of a night shift coping strategy in the adaptation of helicopter pilots (UH-1) to nighttime (2100 to 0100) flying schedules” (Comperatore, Chiaramonte, Pearson, Stone, & Hess, 1993). It appeared that students in dormitories managed their sleep time better than their instructor pilots. Then, they used phase 1 of a two-phase “unit-specific crew rest” strategy to examine shiftwork schedules used by the 1/212th Army Aviation Training Battalion at Fort Rucker, Alabama (Comperatore, Chiaramonte, Lawhorn, & Allan, 1994).

d. Maintenance

Lafleur and Mascorro examined “multishift operations in the aircraft maintenance facilities within the Air Force Logistics Command with a view towards reducing the amount of shift differential paid” (Lafleur & Mascorro, 1974). Meanwhile, LaRue and Metzinger (1974) set out to “identify and evaluate the importance of selected factors of the employees and their environment which might motivate them to work non-day shift schedules in Air Material Area (AMA) Aircraft Maintenance functions of the Air Force Logistics Command.” They found “three sub-factors that were significantly different across shift preference groups. These sub-factors were age, grade classification and salary.”

Two decades later, Maddox (1995) produced an FAA *Human Factors Guide for Aviation Maintenance* that included guidance about shiftwork and scheduling.

Overland (1997) “examined the effects of converting from an 8 hour shift system to a 12 hour system on [USAF] aircraft maintenance personnel.” Overland found that “changing from 8 to 12 hour shifts affected worker well being and morale.” Campbell (1998) examined the effects of converting a large aircraft maintenance squadron from 8-hour shifts to 12-hour shifts and back. Overland found “no significant differences in 8-hour and 12-hour shifts on and off-duty accident rates or day and night shift accident rates. Reported levels of fatigue were significantly greater when 12-hour shifts were used.” Collette (1999) provided a follow-up study of this squadron, from which he concluded that “12-hour shifts have a moderate impact on productivity measurements.”

e. Remotely Piloted Aircraft

Miller conducted an assessment of the shiftwork schedule at the 15th Reconnaissance Squadron, then located at Nellis AFB, in November 2004 (unpublished until now). He found that “schedulers spent large amounts of time assigning individuals to time slots and then making changes on the basis of individual requests and individual needs for deployment, TDY, training, and additional duties. The schedule was quite irregular and largely unpredictable and, thus, there appeared to be a potential for scheduling inequities. Good quality of time off was limited. These problems are known to affect morale and retention.” Miller recommended 12-hour shifts in a DDNNROOS *rota*; i.e., two day shifts (D), two night shifts (N), a protected recovery day (R, the first part of which includes the end of the second night shift), two days off (O), and a stand-by day (S) for limited additional duties. He also recommended how individuals could have flexibility within this schedule without the need for a “scheduler.” Unfortunately, the squadron did not have enough pilots to create the four shift sections needed to implement a reasonable *rota*. They made some changes, but continued working on a poor schedule.

Colleagues of Miller followed up with several excellent reports. Thompson et al. (2006) reported that this schedule “significantly increased the likelihood of personnel reporting symptoms consistent with Shift Work Sleep Disorder.” A follow-up study by Tvaryanas, Platte, Swigart, Colebank, and Miller (2008) “found no significant reduction in reported fatigue despite prior modifications to the shift work schedule. It also demonstrated the potential for inadequate staffing levels to magnify the adverse effects of shift work.” A year later, Tvaryanas and MacPherson (2009) found that “Modeling of feasible variants of the current shift work schedule failed to reveal a significantly improved alternative schedule. Collectively, the results demonstrate a persistent problem with chronic fatigue in this study population, likely reflective of continued inadequate opportunities for recovery and restorative sleep.”

2. Driving

Gold et al. (1992) surveyed 635 nurses, finding that “In comparison to nurses who worked only day/evening shifts, *rotators* had more sleep/wake cycle disruption and nodded off more at work. *Rotators* had twice the odds of nodding off while driving to or from work and twice the odds of a reported accident or error related to sleepiness.” Steele, Ma, Watson, Thomas, and Muelleman (1999) surveyed 1,554 emergency room residents, finding that “Residents reported being involved in a higher number of [motor vehicle crashes] and near-crashes while driving home after a night shift compared with other shifts. Driving home after a night shift appears to be a significant occupational risk for EM residents.”

Barger et al. (2005) collected 17,003 monthly reports from 2,737 interns. They calculated odds ratios for involvement in traffic accidents and found that “Extended-duration work shifts, which are currently sanctioned ... pose safety hazards for interns.” Nesthus et al. (2006) calculated odds ratio risk estimates for air traffic controllers’ “driving outcomes (i.e., lapses of attention, falling asleep, near misses, and accidents). ... Reduced mental sharpness was associated with elevated [odds ratios] while driving to or from most shifts, though the greatest risk was found before early mornings and following midnight shifts.”

De Valck et al. (2007) used a driving simulator with 36 shift workers from a chemical plant and found that “Lane drifting [a sensitive indicator of driver drowsiness] was higher after a night shift than after an afternoon shift”. Scott et al. (2007) collected log books from 895 full-time hospital staff

nurses, completed on a daily basis for 4 weeks. They found that “Shorter sleep durations, working at night, and difficulties remaining awake at work significantly increased the likelihood of drowsy driving episodes.” Dorrian et al. (2008) collected log books for one month from 41 Australian nurses working 1 in 3 shifts, and found that they struggled to remain awake during their commute.

Landrigan et al. (2008) set out to determine whether work hours, sleep, and safety changed after the 2003 implementation of the Accreditation Council for Graduate Medical Education limits for hours of work by resident physicians. They acquired 6,007 reports of near-miss and actual motor vehicle crashes, occupational exposures, self-reported medical errors, and ratings of educational experience from 220 residents and found few changes, including no change in rates of motor vehicle crashes.

Mets, van Deventer, Olivier, Volkerts, and Verster (2009) reviewed the problem of driving safety associated with shiftwork and have proposed countermeasures.

3. Firefighters

Paley and Tepas (1994) sought “differences in time-of-day interactions in firefighters’ sleep length, sleepiness, and mood ratings as a function of shift.” “The study showed that firefighters working on a rotating 8-hour shift schedule will sleep less and will report lower positive mood scores, higher negative mood scores, and greater sleepiness ratings on the night shift. Additionally, it was shown that over the course of a shift (two weeks), firefighters were unable to adapt to changes in their sleep schedule.”

Knauth, Keller, Schindele, and Totterdell (1995) assessed “All 29 operators in the control room of a fire brigade” as they “performed test sessions during work and leisure time at 2-hour intervals on a day with a 14-hour night-shift, a day off and a day with a 10-hour morning shift.” “The circadian rhythm of body temperature was hardly changed by a single night-shift. Parallel to the body temperature, the subjective alertness fell significantly during the night-shift reaching a minimum value at 06:00 h. The mean reaction times increased non-significantly at the end of the night-shift and the results of the two Sternberg memory search tests showed no significant trends. The sleep of the operators after the night-shift was on average reduced to 5 hs 34 min. ... Most results support the conclusion that a 14-hour night-shift without extensive breaks is not acceptable.”

Paul and Miller (2005) assessed five different fire fighter schedules. “All five schedules were predicted to sustain cognitive performance as long as there are no alarms during the night. If night-time alarms occur, impact on cognitive effectiveness occurs similarly across all schedules with recovery of cognitive effectiveness taking up to 48 hrs. However, since schedule 4 provides for 3 days of rest after each 24-hr work period, cognitive performance is fully restored before the next duty period.”

Barger, Lockley, Rajaratnam, and Landrigan (2009) reviewed “the physiologic challenges inherent not only in traditional night or rotating shifts but also in extended-duration shifts and other nonstandard hours.” “The challenging schedules of those in particularly safety-sensitive professions such as police officers, firefighters, and health care providers are highlighted.”

Landrum (2010) noted that “Compressed scheduling offers advantages to a law enforcement agency.” Landrum provided support within the law enforcement community for the shiftwork scheduling principle of *good quality time off*, one of the advantages of compressed work schedules. “When using a compressed scheduling model the agents, their families, and the environment all

benefit. This type of robust scheduling allows full-time employees to complete their work week in fewer days. Agents who report to work fewer days per week have more time for personal events, family events, and respite. A compressed schedule increases morale and recruitment while decreasing attrition.” “It is time for strategic leadership in federal law enforcement to create equilibrium between the agents' vital needs and the mission of securing the United States of America. Implementation of a compressed work schedule for border patrol officers in the United States Border Patrol is clearly a sound strategic decision.”

4. Health Workers

Motohashi (1992) monitored circadian rhythms including salivary cortisol rhythm in seven shift-working ambulance personnel. The data “confirmed the internal desynchronization of the circadian rhythm in physiological rhythms like oral temperature and grip strengths, and was in favour of the hypothesis of an internal desynchronization and clinical intolerance to shift work.” Subsequently, with data from 42 ambulance personnel, Motohashi and Takano (1993) found that “shift work altered the characteristics of circadian rhythms of ambulance personnel; nighttime naps seemed to have a favorable effect on averting changes in circadian rhythms.”

Poissonnet and Véron (2000) reviewed the literature on the “effects on health of irregular schedules in healthcare professionals”. “No conclusive evidence was found to favour any particular work system, although there is evidence that extended workdays (9-12 h) should be avoided as much as possible.”

Kilpatrick and Lavoie-Tremblay (2006) provided advice to managers of shiftwork in healthcare settings, stating that “Guidelines must be developed and initiatives implemented and evaluated to protect health care workers, especially older female shiftworkers, from the negative impact of shiftwork as they represent a precious resource in a shrinking supply.” Choobineh, Rajaeefard, and Neghab (2006) collected data from 432 health care workers at hospitals of Shiraz University of Medical Sciences, Islamic Republic of Iran. They found that “Sleep, social and subjective problems were more prevalent in shiftworkers than day workers. Irregular shiftwork schedules caused more social and subjective problems, as well as work dissatisfaction. Voluntary selection of shiftworking produced fewer health problems.”

Owens (2007) “outlines the causes and consequences of sleep loss and fatigue in healthcare professionals, and provides an empirically based framework for developing strategies to recognize, address, and manage sleep loss and fatigue.” Lockley et al. (2007) provided a review that led them to conclude that “The weight of evidence strongly suggests that extended-duration work shifts significantly increase fatigue and impair performance and safety. From the standpoint of both providers and patients, the hours routinely worked by health care providers in the United States are unsafe.”

A survey was completed recently by 906 healthcare professionals located in Australia, Brazil, Croatia, and the USA, and the data were analyzed by hierarchical multiple regression. The regressions “indicated that particular shiftwork characteristics have differential relevance to indices of work-to-family conflict, physical well-being, and mental well-being” (Barnes-Farrell et al., 2008).

Barger, Lockley, Rajaratnam, and Landrigan (2009) reviewed “the physiologic challenges inherent not only in traditional night or rotating shifts but also in extended-duration shifts and other

nonstandard hours.” “The challenging schedules of those in particularly safety-sensitive professions such as police officers, firefighters, and health care providers are highlighted.”

Barrau-Baumstarck et al. (2009) documented “the role of the type of schedule worked on QoL [quality of life], fatigue, and burnout among critical care nursing and paramedical staff.” “The univariate analysis showed QoL was best in the group working 12-hour shifts, compared with the other 2 groups, while their levels of fatigue and burnout were similar. The multivariate approach, which sought to document the specific role of length of work shift on QoL showed that while the physical component of QoL might be influenced by number of hours worked (staff working 10-hour nights had lower QoL scores than either of the others), but the psychological component was not; only gender and duration of commute were significantly associated with QoL.”

a. Nurses

Nurses have been the focus of and have provided data for many investigations of the effects of shiftwork since about 1990. The issue of night work, nurse health and patient safety became popular in the mid-1980s. For example, Kemp (1984) reviewed 250 relevant articles and concluded that “Research into the effects of night work on females, who predominate in nursing, is very limited.” In the extensive review commissioned by OTA, *Shift Work and Nursing*, Weisman (1989) noted, a number of observations concerning shiftwork in nursing, paraphrased here:

- Nurses on rotating shifts tended to take more sick days than nurses on fixed shifts, and rotating nurses tended to have more serious reasons for taking sick days.
- Nurses on rotating shifts had lower work performance scores than nurses in fixed shifts.
- It was unknown how shiftwork affected patient care.
- Nurses on fixed night shifts and on rotating shifts had more sleep problems than nurses on fixed day or evening shifts. Nurses on fixed night shifts got the least sleep.
- Nurses on rotating shifts had more digestive disorders than nurses on fixed shifts.
- Nurses on rotating shifts had more mood disorders than nurses on fixed shifts.
- Little was known about the effects of shiftwork on the menstrual cycle.
- Nurses on rotating shifts had more disruption of family and social life than nurses on fixed shifts.

Matsumoto, Kamata, Naoe, Mutoh, and Chiba (1996) conducted an extensive study of nurse shiftwork in Japan. They surveyed 152 nurses who worked two consecutive night shifts and two consecutive evening shifts, following a variable number of day shifts. This was a “rapid and counterclockwise rotation” that was used by 71% of the 66 hospitals that they also surveyed. For these nurses, daytime sleep problems were worst after the first night shift and the frequency of taking sleep-inducing drugs was highest; feelings of fatigue were the highest after each of the two night shifts; depression was relatively high; the older the nurse, the greater the aggravation of both sleep problems and fatigue; sleep problems after day shifts were worse and depression was higher in nurses classified as owls compared to those in nurses classified as larks; and there were no differences between introverts and extroverts.

Clissold, Smith, Accutt, and Di Milia (2002) studied “female nurses working a continuous 3-shift roster.” They “found that the average sleep duration per 24-hours across the roster is almost

one hour less for nurses who combine shiftwork, partner and parent roles. In particular, they are not free to use the later starting afternoon shift as an opportunity to repay the sleep debt incurred on night shift. The results show an interaction between work and family roles resulting in chronic fatigue that is a risk factor especially when combined with the acute fatigue associated with night work. ... The strain of shiftwork on personal and social relationships reduces the resources available for coping with the emotional and physical stressors encountered by nurses in their work and family roles.”

Trinkoff, Geiger-Brown, Brady, Lipscomb, and Muntaner (2006) surveyed 2,273 registered nurses about their hours of work. They concluded that “The proportion of nurses who reported working schedules that exceed the recommendations of the Institute of Medicine should raise industry-wide concerns about fatigue and health risks to nurses as well as the safety of patients in their care.” Sveinsdóttir (2006) surveyed 348 nurses in Iceland and found that “Nurses working rotating ... shifts reported a longer working day, more stressful environmental risk factors, more strenuous work and that they were less able to control their work-pace.”

Peate (2007) focused on “some of the consequences of a disrupted circadian rhythm,” provided “advice on coping with shift work, in particular night-time shifts,” and offered “some practical recommendations for practice.” West, Ahern, Byrnes, and Kwanten (2007) surveyed 150 final year undergraduate students over their initial twelve months of clinical practice and concluded that “although it is possible that improved preparation for shift work may assist the adaptation of New Graduate Nurses to shift work during their first year of practice it is clear that attention to the organisation of nursing shift work would also be timely.”

Samaha, Lal, Samaha, and Wyndham (2007) assessed chronic fatigue, anxiety, mood, locus of control, and a number of lifestyle factors in 111 eldercare shift-worker nurses. They found that “mood disturbance, locus of control and trait anxiety are statistically significant predictors of chronic fatigue. Poor sleep quality was the lifestyle factor which most strongly contributed to fatigue. ... Whilst problem-focused coping behaviours were not associated with fatigue, coping by using alcohol, letting emotions out and avoiding the situation significantly predicted chronic fatigue.”

Dorrian et al. (2008) acquired one month of logbooks from 41 Australian nurses. They found that “Nurses reported exhaustion, stress and struggling to remain (STR) awake at work during one in three shifts. Sleep was significantly reduced on workdays in general, and workdays when an error was reported relative to days off. The primary predictor of error was STR, followed by stress. The primary predictor of extreme drowsiness during the commute was also STR awake, followed by exhaustion, and consecutive shifts. In turn, STR awake was predicted by exhaustion, prior sleep and shift length.” Karagozoglu and Bingöl (2008) surveyed 418 Turkish nurses, finding that, in general, nurses’ sleep quality was low and job satisfaction was at a moderate level, and that as sleep quality scores increased, job satisfaction ratings increased.

Peters, de Rijk, and Boumans (2009) examined whether “satisfaction with irregular working hours that are a form of shiftwork operates as a mediator between work and home characteristics and health problems.” “All work characteristics, but no home characteristics, were associated with satisfaction with irregular working hours. The work characteristics ‘job demands’ and the home characteristics ‘autonomy at home’ and ‘home demands’ were associated with health. Satisfaction with irregular working hours did not mediate between work/home characteristics and health. Those reporting more social support, lower job demands and more job autonomy were more satisfied with their irregular working times that were a form of shiftwork.”

Studies of rotating versus fixed shifts for nurses were described in the section on Schedule Structure, above, as were studies of 12-hour shifts. There have been at least two studies of 16-hour night shifts for nurses (Fukuda, Takahashi, & Airta, 1999; Takahashi et al., 1999). Josten, Ng-A-Tham, and Thierry (2003) investigated the effects of 9-hour shifts in nursing, using questionnaires completed by 134 nurses from three nursing homes in The Netherlands. "The 9-hour shift seemed to combine the negative aspects of the 12-hour shift with the negative aspects of the 8-hour shift. It is suggested that the 9-hour shift had more negative effects than the 12-hour shift."

Borges and Fischer (2003) studied sleep disturbances in night-shift nurses and Ribeiro-Silva et al. (2006) napping. De Martino (2002) conducted a sleep study that indicated the need for naps during the night shift. Boivin and James (2002) tested the efficacy of an intervention with bright light therapy and work and light-protection goggles, while Grundy et al. (2009) assessed light exposure and melatonin levels. These studies are described in the section on Health and Fatigue Countermeasures, respectively. Two studies of driving safety were described, above, in the present section (Dorrian et al., 2006; Scott et al., 2007).

Samples of the nurse population have been studied with respect to general health, breast cancer prevalence and melatonin suppression, and other issues. Those studies are all described, below, mainly in the sections on Health and Individual Differences.

A number of reviews and guides for nurses in shiftwork and their managers have been produced (Admi, Tzischinsky, Epstein, Herer, & Lavie, 2008; Alward & Monk, 1994, 1993; Berger & Hobbs, 2006; Circadian Technologies, 2005; Erenstein & McCaffrey, 2007; Surani, Murphy, & Shah, 2007; West, 2001; Wilson, 2002).

b. Residents

Physicians have also been the focus of and have provided data for many investigations and innumerable discussions of the effects of shiftwork. Michaels described the problem as it stood in 1984: "The deleterious effects of night shift work are discussed in relation to emergency physicians. Much of the early research is drawn from heavy industry sources and must be extrapolated to medical work. Disruption of circadian rhythms and Zeitgebers, caused by adherence to contemporary social schedules, causes recurrent difficulty for physicians who constantly change schedules. Adjustments in both physical surroundings and social structure that can make the effects of traumatic schedule change more tolerable are discussed." Whitehead, Thomas, and Slapper provided a review in 1992.

Investigations of residents' driving safety were discussed, above (Barger et al., 2005; Steele et al., 1999). The experimental use of modafinil by residents is discussed in the Fatigue Countermeasures section below (Gill, Herich, Westcott, Godenick, & Tucker, 2006; Suryadevara, Zandifar, Guyer, & Kellman, 2008).

Steele, McNamara, Smith-Coggins, and W. Watson (1997) surveyed more than 2,000 emergency medicine residents with regard to lark-owl tendencies and found that they tended "slightly toward eveningness." Surveys acquired from nearly 1,000 other emergency medicine residents allowed Steele et al. (2000) to characterize residents' working hours and shiftwork tolerance. They concluded that "residents generally tolerate shiftwork well and prefer 8-hour or 10-hour shift lengths compared with 12-hour shift lengths."

Smith-Coggins, Rosekind, Hurd, and Buccino (1994) monitored six physicians electronically for two 24-hour periods, one with daytime work and the other with nighttime work.

They found that “Attending emergency physicians get less sleep and are less effective when performing manual and cognitive tests while working night shifts with day sleep compared with working day shifts with night sleep.” A subsequent intervention “failed to significantly improve attending physicians’ sleep, performance, or mood on night shifts.”

Dula et al. (2001) sought to determine whether working five serial night shifts in the emergency department results in a decline in physician performance as measured with an intelligence test. They concluded that “Working a series of 5 night shifts results in a substantial decline in cognitive performance in physicians working in the ED.” Rollinson et al. (2003) assessed the neuropsychological performance of 12 interns at the beginning and end of a shift while they worked consecutive night shifts in the emergency department. They found that “Interns working nights demonstrated a significant reduction in visual memory capacity across the night shift.” Lockley et al. (2004) quantified work hours, sleep, and attentional failures among 20 first-year residents working a traditional rotation schedule that included extended work shifts or working an intervention schedule that limited scheduled work hours to 16 or fewer consecutive hours. “Eliminating interns’ extended work shifts in an intensive care unit significantly increased sleep and decreased attentional failures during night work hours.” Gander et al. (2008) examined work patterns, sleep, and performance of 28 anesthesia trainees and 20 specialists across a two-week work cycle in two urban public hospitals. “Consistent with observations from experimental studies, the sleep loss of specialists across 12 consecutive working days was associated with a progressive decline in post-duty psychomotor vigilance task performance. However, this decline occurred with much less sleep restriction ... than in laboratory studies, suggesting an exacerbating effect of extended wakefulness and/or cumulative fatigue associated with work demands.”

Eastridge et al. (2003) hypothesized that “call-associated” acute sleep deprivation has no effect on technical dexterity as measured on a minimally invasive surgery trainer, virtual reality (MIST VR) surgical simulator. Data from 35 surgical residents indicated that “Call-associated sleep deprivation and fatigue are associated with increased technical errors in the performance of simulated laparoscopic surgical skills”. DeMaria, McBride, Broderick, and Kaplan (2005) assessed 17 surgical residents’ learning of laparoscopic skills before and after night call. “Most parameters ... showed improvement rather than deterioration post-call, which is consistent with learning of laparoscopic skills despite lack of sleep from night call.” Leff et al. (2008) assessed the impact of seven successive night shifts on the technical surgical performance of 21 junior residents. They found that “Newly acquired technical surgical skills deteriorate maximally after the first night shift, emphasizing the importance of adequate preparation for night *rotas*. Performance improvements across successive shifts may be due to ongoing learning or adaptation to chronic fatigue.”

Landrigan et al. (2004) examined the rates of serious medical errors made by interns while they were working according to a traditional schedule with extended (24 hours or more) work shifts every other shift (an “every third night” call schedule) and while they were working according to an intervention schedule that eliminated extended work shifts and reduced the number of hours worked per week. “Interns made substantially more serious medical errors when they worked frequent shifts of 24 hours or more than when they worked shorter shifts.” Barger et al. (2006) used the monthly reports cited in the sub-section, Driving, above, to assess whether extended-duration shifts worked by interns were associated with significant medical errors, adverse events, and

attentional failures. They found that “extended-duration work shifts were associated with an increased risk of significant medical errors, adverse events, and attentional failures in interns.”

McDonald, Ramakrishna, and Schultz (2002) developed a spreadsheet model of residents’ work hours in the United States. The model allowed the input of multiple parameters (i.e., call frequency, call position, days off, short-call, weeks per rotation, outpatient weeks, clinic day of the week, additional time due to clinic) and start and stop times for post-call, non-call, short-call, and weekend days. The model was validated and then used to test proposed scenarios. The investigators concluded that the “model is sufficiently robust to accurately estimate work hours on multiple and varied *rotations*.” They used the model successfully “to test proposed alternative scenarios, to overcome faculty misconceptions about resident work-hours ‘solutions,’ and to make changes to our call schedules that both are realistic for residents to accomplish and truly diminish total resident work hours.”

A number of articles have addressed hours of service for junior physicians in the United Kingdom (Ahmed-Little, 2008; Cass, Smith, Unthank, Starling, & Collins, 2003; Douglas, 2008; Jaggi & Surender, 2004; Kapur & House, 1998; Pounder, 2008; Reid & Coakley, 2008; Vallely, 1991).

General reviews and guidance concerning residents’ work hours have been provided in several articles (Fletcher et al., 2005; Goldstein, Kim, Widmann, & Hardy, 2004; Kuhn, 2001; McLean, 2005; Mion & Ricouard, 2007).

5. Maritime

a. Surface

The traditional 4-hour shift (watch) length is used in many, but not all, military and commercial maritime surface operations. The nature of this schedule is described in detail by Miller in Attachment 2 of his shiftwork manual (Miller, 2006). The main problems with the traditional 4-and-8 maritime watch plan are reduced total sleep time and fragmented sleep. With only eight hours off between watches, the watchstander is never able to get the eight hours of continuous, uninterrupted sleep found by clinicians and researchers to be the average sleep need. Thus, many maritime watchstanders operate at a continual, unacceptably-low level of cognitive performance effectiveness (usually about 80% to 90%) while the vessel is underway.

Condon et al., (1984) and Knauth et al., (1984) collected oral temperature data from 12 members of the crew of an oil tanker at sea, 9 of whom stood 4 on, 8 off fixed watches. The data showed sleep interference caused by the watch schedule (Knauth et al., 1984) and suggested “that a reasonable degree of adjustment of the temperature rhythm to the different sleep/wake routines imposed by the work system had occurred. ... However, further investigations are needed to substantiate these findings, and also to determine how long it takes for the rhythm adjustment process to reach completion in inexperienced workers” (Condon et al., 1984).

Colquhoun (1985) reviewed the problems associated with hours of work and watchkeeping duties on ocean-going vessels sailing between distant ports. Research findings from submarine studies in the United States in 1949-1950 (see next section) were considered, as were the studies by Colquhoun, Blake, and Edwards reported in 1968-1969 (Colquhoun, Blake, & Edwards, 1968, 1969; Colquhoun, Blake, & Edwards, 1969; Colquhoun, Blake, & Edwards, 1968) and the submarine crew watch comparison by Caille and Bassano (1977; see next section). Colquhoun (1985) discussed these findings “in relation to a proposed program of research aimed at determining the optimal system

for maintaining efficiency in crews operating the modern, fully automated vessels now coming into service.” This proposed program may have resulted in a 1987 study (Colquhoun, Watson, & Gordon, 1987) and the “Work at Sea” publications cited below.

Ely (1987) reviewed U.S. Coast Guard watchstanding schedules and collected questionnaire data. He reported that “Results indicate that there are minor differences between performance during day watches and performance during night watches. Similarly, the study indicated that performance within a given watch declines as time on watch increases for day watches only; this pattern does not hold for night watches.”

According to Blassingame (2001),

Lauer III (1991) evaluated a segment of the surface warfare officer (SWO) community assigned to shipboard command and control functions in a certain operational condition. He reported that a great percentage of the tactical action officers (TAOs) and officers of the deck (OODs) experienced systems of sleep deprivation while underway and a very small percentage of the TAOs and OODs felt they were fully alert at all times. The restricted nature of Lauer’s thesis prevents full publication of actual percentages; authorized personnel should refer to his thesis for specific numbers.

Boulard, Telle-Lamberton, and Vezina (1989) (as reported by Donderi et al., 1995) studied four crewmen on the 0000 to 0600h and 1200 to 1800h 2-section watches, four crewmen on the complementary 2-section watch, and five crewmen who worked 0600 to 1930h during a month of Canadian Coast Guard winter search and rescue operations. The comparisons of physiology and performance among these three small groups produced no useful differences. Boulard et al. (1989) recommended the use of three watch sections, including three fixed 8-hour watches starting at 2200h.

A series of “Work at Sea” articles appeared in 1988 from a group of investigators in the United Kingdom, dealing with circadian rhythm disruption in maritime crews (Colquhoun et al., 1988; Condon et al., 1988; Fletcher, Colquhoun, Knauth, De Vol, & Plett, 1988; Plett et al., 1988; Rutenfranz et al., 1988). Condon et al. (1988) collected daily records of sleep, activity, body temperature, performance, and subjective alertness from 15 watchkeepers on the 4-on/8-off system, and from 28 dayworkers, on both westward and eastward transatlantic voyages. They observed less daily sleep on the eastward voyage than that on the westward voyage, and lower quality. “[M]orning levels of all [circadian] variables were lower on the eastward voyage than on the westward, but evening levels were higher. ... This problem can only be solved by the development of alternative watchkeeping systems which take full account of these rhythms.” Plett et al. (1988) assessed the physiological variables of the seamen and concluded that, for the watchkeepers, “full phase adjustment of the circadian rhythms to shifted hours of work did not occur.” Rutenfranz et al. (1988) examined the sleep patterns of the seamen. They observed that “All watchkeepers exhibited fragmented sleeping patterns, which indicated a lack of adaptation of the sleep/wakefulness cycle to the hours of work. ... A solution for this problem could perhaps be a new, stabilized system that allows a single uninterrupted sleep, which is required for full recuperation, to be taken each day.” Fletcher et al. (1988) investigated the use of a compressed schedule while underway, with mixed results.

Donderi, Smiley, and Kawaja (1995) compared “a new [2-section] 4&8 schedule to the current [2-section] 6&6 schedule with regard to performance, mood and sleep”. “The two schedules

were not significantly different in total sleep, performance (choice reaction time, short term memory) or mood. ... We do recommend that the Coast Guard consider a variation of the 4&8 schedule wherein the dayworker remains on the 4&8 schedule (which improved sleep length) and the night worker remains on the 6&6 schedule (6&6 nightworkers slept better).” In their review of the literature, Donderi et al. (1995) found only six previous studies of 2-section watchkeeping schedules: Strong and Brown, (1989); Boulard et al., (1989); Wilkinson and Edwards, (1968); Colquhoun et al., (1975); and Colquhoun et al., (1969). These studies are listed in this bibliography as reported by Donderi et al. (1995) and by Colquhoun (1985).

Sanquist, Raby, Maloney, and Carvalhais (1996) assisted the United States Coast Guard (USCG) in undertaking “a multi-year research program to establish a technical basis for maritime operational practice and regulatory guidance in work-rest scheduling and work hour limitations.” In this study, data were acquired from 141 mariners on eight commercial ships. The investigators found that the “incidence of critical fatigue indicators such as severely restricted sleep durations per 24-hour period, very rapid sleep onset times, and critically low alertness levels suggest that fatigue regularly occurs. The results point to sleep disruption, reduced time between watches, fragmented sleep, and long workdays as principal contributors to the problem.” Several courses of action for fatigue reduction were discussed.

Miller, Smith, and McCauley (1998) investigated crew fatigue on three types of USCG cutters. “Evidence of mild fatigue, specifically daytime sleepiness and a degradation of vigilance performance, was observed in many crew members. This study documented levels of workload, performance, and fatigue found in normal, daily Coast Guard cutter operations. Principles of industrial chronohygiene were considered in light of the analysis of crew member sleep patterns, circadian rhythms, and watch schedules. This analysis led to recommendations for watch schedule alternatives that may reduce the probability of crew daytime sleepiness and vigilance performance degradation.”

Comperatore, Kirby, Bloch, and Ferry (1999) evaluated crew alertness and the incidence of sleep/wake cycle disruptions for 30 crewmembers aboard a USCG cutter during 32 days of low-tempo underway operations. Wrist activity monitors and short-duration, electroencephalographic (EEG) alertness tests were used. The data “revealed a 59 percent incidence of sleep/wake cycle disruption associated with high failure rates in the EEG alertness tests. ... participants exposed to frequent watch *rotations* showed disrupted sleep associated with the 0000-0400 and 0400-0800 watch schedule.” A crew endurance education program was recommended.

Nguyen and Miller (Miller, Nguyen, Sanchez, & Miller, 2003; Nguyen, 2002) examined the effects of reversing the work-sleep schedules of the crew aboard an aircraft carrier involved in night combat operations. Nguyen (2002) found “that a significant number of sailors have difficulty adjusting to working nights and sleeping days. Additionally, the study finds that individuals working topside have greater difficulty adjusting to the reversed schedule than do their counterparts who work belowdecks.” Sawyer (2004) assessed sailor mood during this same period. “The results showed that younger participants were angrier than older participants on night shiftwork. The results also indicated that there was a significant interaction between repeated measures of mood states and gender. In addition, female participants reported significantly higher mood scale scores than the male participants, and topside participants were getting significantly less sleep than belowdecks participants.”

Haynes (2007) used wrist activity monitors and the Fatigue Avoidance Scheduling Tool (FAST) to predict the waking effectiveness level of sailors aboard DDG-93. “The results showed that the Navy Standard Workweek does not accurately reflect the daily activities of Sailors.”

Gander, van den Berg, and Signal (2008) monitored the sleep and sleepiness of commercial fishermen at home and during extended periods at sea while working a nominal 12 h on/6 h off schedule. “On the 12 h on/6 h off schedule, there was still a clear preference for sleep at night. Comparing the last three days at home and the first three days at sea showed that fishermen were more likely to have split sleep at sea.” ... “[O] 23% of days at sea, fishermen obtained < 4 h total sleep/24 h, compared to 3% of days at home. ... [S]leepiness ratings remained higher after sleep at sea.”

Härmä, Partinen, Repo, Sorsa, and Siivonen (2008) examined fatigue and sleepiness in 185 Finnish bridge officers, 42% of whom worked two 4-hour watches per day, while 26% worked two 6-hour watches per day. Ninety-five officers completed a sleep diary for 7 consecutive days at sea. “Compared to the 4/8 watch system, the officers working the 6/6 watch system reported shorter sleep durations, more frequent nodding-off on duty ... and excessive sleepiness ... Subjective sleepiness was highest at 04:00 and 06:00 h. ... Severe sleepiness at 04:00-06:00 h was especially problematic in the 6/6 watch system among evening types ... The results suggest the 6/6 watch system is related to a higher risk of severe sleepiness during the early morning hours compared to the 4/8.”

b. Submarine

Large proportions of submarine crews work and sleep in low-level lighting conditions, separated from strong photic *Zeitgebers* (Hunt & Kelly, 1995). It is possible that the influence of social *Zeitgebers* is enhanced in this environment (Aschoff et al., 1971). However, as Mistlberger and Skene (2004) noted, additional research on this issue is needed.

(1) Three-Section Watches. An alternative to the standard, fixed 4-and-8 watchstanding schedule was proposed in 1949 to the submarine fleet by Dr. Nathaniel Kleitman, later to become the father of sleep research. Work compression was used within each watch section to allow non-watch periods of 10 hours and more per section while maintaining 8 hours of watch per section per day. “On the basis of the body temperature studies, the proposed schedule was found to be a definite improvement over the present one” (Utterback & Ludwig, 1949).

As noted above, in the Circadian Rhythms section, Colquhoun et al. (1978, 1979) had the opportunity to collect temperature data (at 3-hour intervals) from eight submarine sonar men during a 48-day cruise. On the basis of their observations and parallel observations of body temperature cycles in four officers standing fixed, 8-hour work periods, Colquhoun et al. (1978; Colquhoun, 1985) recommended using a 1-in-3, 8-hour fixed work schedule in submarines. Alternatively, they recommended a modification of the schedule suggested by Kleitman in 1949 in which the 8 hours of work are completed within a fixed, 12-hour period (close work). They expected that the fixed periods would allow rapid re-alignment circadian rhythms with the new work-rest schedule in the first week of the cruise, and that the 16-hour off period would prevent sleep fragmentation and restriction.

According to Caille and Bassano (1977), the French Navy used a variable, “anhemeral” watch schedule with a 72-hour cycle and watches of 4 and 4 hours each day or 5 and 3 hours each day. The investigators were able to compare this schedule with a fixed, “hemeral” schedule during the simulation of a 30-day submarine mission with a volunteer crew of 24 men. “The strong advantage of the second alternative compared to the first is evidenced in the sleep process, behavioral efficiency, mood, and circadian biochemical parameters.”

U.S. Navy submarines began operating on an 18-hour work-rest cycle with 6-hour watches in the 1960s, in accord with a recommendation by Kleitman (Kleitman, 1949; Kleitman & Jackson, 1950). All watchstanders stood watch for six hours and were then off for 12 hours. Then they repeated the cycle. Subsequently, Stolgitis (1969) theorized that the 6-and-12 schedule would encourage better performance among crewmembers. On the 18-hour work-rest cycle, watchstanders slept about seven hours per 24 hours (Kelly, Grill, Hunt, & Neri, 1996; Kelly Grill, Ryman, Hunt, Dijk, Mitchell, et al., 1996; Kelly, Ryman, & Pattison, 1996).

However, the 18-hour work-rest cycle, coupled with the absence of strong photic *Zeitgebers* (daylight-darkness time cues), caused the circadian rhythms of the watchstanders to desynchronize from the 24-hour daily cycle (Naitoh, Beare, & Biersner, 1983) and, in some cases, free run with a period of about 24.5 hours instead of entraining to the 24-hour clock (Kelly, Grill, Ryman, Hunt, Dijk, Mitchell, et al., 1996). Also, some watchstanders developed 18-hour cycles in addition to 24-hour cycles (Schaefer, Kerr, Buss, & Haus, 1979). The inability of the watchstanders’ circadian rhythms to entrain to an 18-hour work-rest cycle was not surprising: the limits of entrainment were shown in recent years to be about a 23- to 27-hour cycle in dim light (Wever, 1986; Wever, Poláscaronek, & Wildgruber, 1983).

An alternative to the 18-hour cycle schedule proposed by Miller et al. (1998) was investigated in the laboratory and tested twice while underway (Duplessis, Miller, Crepeau, Osborn, & Dyche, 2007; Miller, Dyche, Cardenas, & Carr, 2003; Osborn, 2004). The schedule did not appear to allow adequate scheduling of drills and training. Presently, the U.S. Navy is considering fixed 8-hour shifts for submarine operations.

Blassingame (2001) used data from the U.S. Naval Submarine Medical Research Laboratory’s Watchstanding Survey (shown in the report as Appendix F) to help determine “what a sub-sample of this population think about their sleep habits and ... if there are differences in the reported amount of sleep between sailors in four different operational environments: 1) at sea, 2) in port, 3) on shore duty, and 4) on leave.” Findings included “a positive correlation between the amount of sleep obtained and the desired amount of sleep to function at every operational condition.” “Submariners reported getting less sleep while ‘at sea’ than other conditions;” and “the inference that subjects who report needing more sleep do indeed get more sleep.” However, “When in the ‘at sea’ condition, this correlation was much weaker indicating that subjects have much less control over the amount of sleep they get when deployed.”

(2) Two-Section Watches. The submarine fleets of U.S. allies, including the United Kingdom, Canada, Australia, and The Netherlands are restricted by submarine construction techniques to two watchstanding sections. In a two-section plan, each watchstander works 12 hours per day (actual) on every day. This arrangement means that half the crew is manning the ship at any given time. Often, the two sections are called the “Port Watch” and the “Starboard Watch,” based

upon an ancient practice of a section sleeping on one side of the ship or the other. This solution is quite fatiguing: each section must work at least $(168 \text{ hrs}/2 =) 84$ hours per week. The watches kept on the square-rigged barques or windjammers of the late 19th century and in the British Royal Navy consisted of five 4-hour periods and two 2-hour periods (dog watches). This pattern allowed the two sections to alternate from day to day, so that the Port section had the mid-watch one night and the Starboard section had it the next night.

In the often-used port-starboard plan, the two sections may alternate at 6-hour intervals or at 12-hour intervals. These schedules may start at midnight or at other hours. For example, the 6 and 6 schedule may start at 0300h, and the 12 and 12 schedule may start at 0600h. In some cases, two watchstanders who perform the same task may alternate at less regular intervals. The 6 and 6 schedule may be dogged. For example, start at midnight and dog the afternoon watch: 1200 to 1500h and 1500 to 1800h. The 12 and 12 plan also may be dogged by breaking the afternoon watch into two 6-hour watches: 1200 to 1800h and 1800 to 0000h. Alternatively, one might wish to dog the mid-watch: 0000 to 0600h and 0600 to 1200h.

Wilkinson and Edwards (as reported by Donderi et al., 1995) conducted a shore-based investigation of a 2-section, 7-5-5-7-hour watch schedule (a mealtime-oriented modification of the 6 and 6 schedule), with main sleep times from 0000 to 0700h and 1700 to 0000h (Wilkinson & Edwards, 1969). The amplitude of the circadian rhythm in body temperature was flattened, but the performance decrements during the night shift were minimal. Wilkinson and Edwards (1969) noted that "In vigilance-type tasks calling for sustained attention it is probably the job rotation which is important; in more intense cognitive tasks such as complex decision-taking it may be the stabilization of daily shift times which confers the advantage, with job rotation doing more harm than good." However, they also noted the limited applicability of shore-based experimental results to at-sea operations due to differences in the timing of sleep.

Strong and Brown (1989; as reported by Donderi et al., 1995) assessed eight control room personnel, four on each watch, over 14 days while underway. Many data points were missing, but it appeared that the port watch (the "day" watch) suffered a greater decline in performance than the starboard watch.

Chapman (2001) measured the sleep-wake cycle of 25 submariners by wrist actigraphy and sampled their saliva for melatonin levels during a week underway. This crew stood 2-section watches of 6 hours on and 6 hours off starting at 0100h. Chapman also acquired similar data from 22 submariners standing a 3-section watch and 10 on a 2-section watch during a 12-day transit. Submarine lighting issues and the interactions among sleep, circadian rhythms and operational schedules were reviewed. Chapman noted the following fatigue symptoms: (1) slowed speech, (2) delayed response to orders, (3) greater number of malapropisms and incorrect sequencing of orders, (4) delayed repetition of orders, (5) failure to acknowledge orders, (6) increase in vacant stares, irritability and minor altercations between personnel, and (7) decreased ability to acknowledge multiple sources of information during longer periods at sea.

Though the specific results of the data acquisition were not reported, Chapman (2001) made comprehensive recommendations for a fatigue management system in submarine operations. These recommendations included:

- a) watch systems and scheduling, sleep management and strategic napping in the COLLINS-class environment;

- b) development, practice and adherence to sleep management plans for personnel;
- c) exploring the inclusion of personnel redundancies for those departments experiencing high cognitive load (to assist in more effective fatigue management); and
- d) modification of task rotation and time of completion to measure cognitive workload and minimise effects of sleep loss (p. 4).

Eriksen, Gillberg, and Vestergren (2006) investigated subjective sleepiness and sleep duration in connection with a 6 h on/6 h off duty system for 66 hours in a bridge simulator, with two watch sections of 12 officers each, very similar to those found on ships. "The results showed that the average level of sleepiness was significantly higher during the 00:00-06:00 h watch compared to the 12:00-18:00 h and 18:00-24:00 h watches, but not to the 06:00-12:00 h watch. Sleepiness also progressed significantly from the start toward the end of each watch, with the exception of the 06:00-12:00 h watch, when levels remained approximately stable. ... Sleep duration during the 06:00-12:00 h off-duty period (3 h 29 min) was significantly longer than during the 12:00-18:00 h period (1 h 47 min) and the 18:00-24:00 h period (2 h 7 min). Sleep during the 00:00-06:00 h period (4 h 23 min) was longer than all sleep periods except the 06:00-12:00 h period. ... In spite of sufficient opportunities for sleep, sleep was on the average around 1-1 h 30 min shorter than the 7-7 h 30 min that is considered 'normal' during a 24 h period. ... An initial suppression of sleepiness was observed during all watches, except for the 06:00-12:00 h watch. This suppression may be explained by the "masking effect" exerted by the relative high levels of activity required when taking over the responsibility of the ship. Toward the end of watches, the levels of sleepiness progressively increased to relatively high levels, at least during the 00:00-06:00 h watch. Presumably, initially high levels of activity are replaced by routine and even boredom."

Paul, Nesthus, and Miller (2008) conducted an at-sea trial with wrist-actigraph sleep data and unalerted response time data from 21 submariners while underway to model the impact of the watch schedule on crew cognitive effectiveness. Three subjects were non-watch-standers, 6 were from the 1-in-2 backwatch, 6 were from the 1-in-2 front-watch, and 6 were from the 1-in-3 engineers' watch. "The data indicated increasing difficulty arising from sleep and a decrease in subjective levels of 'restedness' over days at sea. Alertness also decreased over days at sea. ... While there was no difference in sleepiness between watch system variants or over days at sea, sleepiness levels were consistently elevated to mid-scale levels. Difficulty concentrating, slowed reactions, level of fatigue, work frustration and physical discomfort increased during the trial relative to the pre-trial baseline." The investigators recommended that "An alternative watch schedule which is more sparing of submariner cognitive effectiveness should be developed and implemented, if possible."

6. Military

Hull's "Military Applications of Circadian Rhythm Principles," prepared for the U.S. Congressional Office of Technology Assessment (OTA), provided an excellent, landmark summary of what was known about the interactions of biological rhythms with the demands of 24/7 operations in the aftermath of Operation Desert Storm (Hull, 1990; OTA, 1991). After examining schedules for ground, air, and maritime operations, Hull noted that "Decisions concerning the disposition and activities of personnel are guided by the demands of a given situation, and the effects of performance decrements due to biological rhythm upset, fatigue, and other factors may be accepted rather than

mediated in some wartime circumstances. A better understanding of those decrements and their effects will ultimately aid military commanders in balancing the various factors that go into making such decisions.” Fundamentally, Hull reviewed and summarized scientific evidence in support of Napoleon’s admonition to his commanders almost 200 years earlier, “You must not needlessly fatigue the troops” (Napoleon Bonaparte, to the Armée d’Italie in 1796).

Pearson examined and modeled in FASTTM (described below) the work and sleep patterns of workers who tested developmental and operational electromagnetic equipment at the Benefield Anechoic Facility at Edwards Air Force Base, California, where employees’ work hours were often extended considerably to meet test schedules (Pearson, 2004). “The results demonstrated that as the week progressed and the volunteers’ sleep decreased, the effectiveness of their work performance correspondingly decreased to a level where the safety of the test and the volunteers were both at risk.”

Cosenzo, Fatkin, and Branscome (2005) identified various metrics that assessed the cognitive processes used by individuals to make decisions. One objective of this study was to assess the utility of those metrics for predicting performance in a multitask environment, an emergency operations center. The second objective was to examine the effect of work shifts and cognitive uncertainty on performance in the same environment. “Results showed that individual differences in coping with uncertainty were related to call time.”

Miller et al. (2005) evaluated an Internet-based survey, conducted during the fall and winter of 2003-2004, to help assess the impact of U.S. Air Force shift worker fatigue on ground mishaps and operational errors. Of 9,242 respondent 5,890 were shiftworkers and 1,866 were shift supervisors and schedulers. “The survey results prompted recommendations concerning fatigue management and sleep hygiene training, off-duty employment, shift work scheduling and worker rest policies, operational risk management for fatigue effects, crew-rest periods, reporting fatigue-related incidents, manpower and personnel planning, shift lengths, rotation speeds, schedule predictability and equity, coming in to work on days off an automated shift work scheduling tool, and possible relationships between shift work and suicide.”

7. NASA

The biological rhythm disturbances encountered by Shuttle astronauts working two 12-hour shifts in orbit are not discussed here. Shiftwork operations for ground controller personnel have been examined by several investigators (Hayes, Stewart, & Eastman, 1994; Kelly, Rosekind, Dinges, Miller, & Gillen, 1994; Kelly et al., 1998; Stewart & Hayes, 1994; Wegmann, Gundel, Klein, & Samel, 1987).

8. Nuclear

The core meltdown in Unit 2 at the Three Mile Island (TMI) nuclear power plant occurred at 0400h in March 1979. It was caused primarily by mechanical failures, compounded by the failure of the mid shift to diagnose the problem correctly and by poor control room display design. Though not mentioned specifically in reports, it was rested personnel who diagnosed the malfunction correctly and prevented a tragedy.

In 1982, DiSalvo and Pittman noted, “Since the TMI incident considerable interest has been focused upon the human factor aspects of nuclear power plant operation. One of the concerns has been the effects of shift work (rotation and length) and overtime on operator performance. In its

request for human factors research (RR-NRR-81-2), the Office of Nuclear Reactor Regulation requested research be performed to identify the effects of shift work and overtime on operator performance” (DiSalvo & Pittman, 1982). In this report, the NRC staff determined “the adequacy of using the Licensee Event Reports (LERs) to evaluate: the effects of shift work and overtime on human performance in nuclear power plants, and the statistical nature of human error in nuclear power plants; and given that the LERs are adequate to draw statistical conclusions about human performance in nuclear power plants.”

Preuss, Herbert, Reinartz, and Saniter (1984) reviewed fundamental chronobiological knowledge with respect to the effects of rotational shiftwork on operator performance, particularly in the nuclear power industry. Smiley and Moray (1989) addressed the safety-related aspects of the use of 12-hour shift work schedules at nuclear power plants. They examined the current literature for information on accidents, fatigue and personal preferences, and interviewed operators and maintainers. “Several factors related to 12-hour schedules were identified which could affect safety, but which have not been adequately considered.”

Baker (1995) noted that “A growing number of nuclear power plants in the United States have adopted routine 12-hr shift schedules.” Baker described a study of simulated 8-hr and 12-hr work shifts that compared “alertness, speed, and accuracy at responding to simulator alarms, and relative cognitive performance, self-rated mood and vigor, and sleep-wake patterns of 8-hr versus 12-hr shift workers.”

9. Other Occupations

Levin, Oler, and Whiteside (1985) noted that “Reports of work accidents and increased absence due to sickness among shift workers have suggested that their work performance and health are adversely affected by interference with the body’s normal circadian or biological rhythm. Since the rotating shift is the most disruptive of the work regimens, an investigation was undertaken of the reportable occupational injuries of 1700 paint production and associated employees of one company working only on rotating shift.” “[S]ome time-of-day and circadian effects were indicated by an increased rate of accidents on the night shift, particularly during the last 3 h of the shift.”

Wojtczak-Jaroszowa and Jarosz (1987) analyzed 2,772 accidents in two plants, finding a “circadian rhythm of accidents.” This rhythm was “governed by the interrelationships between the following endogenous and exogenous rhythmic factors: human factors, such as fatigue and circadian fluctuation of biological functions; and multiple hygienic and social components.” “In both plants, the circadian rhythm of accidents was approximately parallel to the circadian rhythm of activity of the plant as a whole rather than to the activity of shift workers only, with a peak around 1100 hr. The lowest number of accidents was noted during night shifts; some increase was observed after midnight, however, in spite of the lowest level of plant activity at that time.”

These findings underscored the need to take into account the numbers of operations that occur, i.e., the exposure to risk, at varying times of day and across shifts. Without knowledge of exposure, one runs the risk of underestimating risk when exposure is low. Harris (1978) emphasized this issue in his classic circadian analysis of the risk of single-vehicle accidents in commercial trucking.

Novak, Smolensky, Fairchild, and Reves (1990) provided a retrospective study of 242 shiftworker and 224 nonshiftworker injuries at a chemical manufacturing plant. The shift schedule used 8-hour shifts and a 7-day backward rotation. Overall injury incidence rates were not significantly

different between the two groups. The “average number of injuries was two-three times higher during the first four days of the day and night shift, yet were not elevated during the evening shift.”

Chan et al. (1993) examined health complaints, blood pressure, sleep and sickness absence experience in 308 female electronics workers for at least one year on 12 h shifts. Two-hundred fifty three workers were on permanent shift schedules and 55 were on rotating shift schedules; 75 8-hour day workers acted as controls. “Although subjects on the night shift had shorter sleep than controls and 12h day workers, only the group on rotating schedule had a higher proportion of workers who did not sleep well compared to the controls. ... The results indicate no serious health problems among workers on 12 h shift for over a year.”

Cantwell (1997) addressed general circadian, sleep loss and shiftwork topics for ship production. Cantwell discussed how “These factors affect the quality and safety of the product, process and personnel, and should be considered throughout all phases of design, management and production.”

Prunier-Poulmaire, Gadbois, and Volkoff (1998) examined “the combined impact of different shift schedules and job demands on the physical health of customs officers.” “The analyses highlighted the dominating effect of the 3x8 hour and 4x6 hour schedules on the occurrence of health problems but also showed strong effects for confrontation with travelers. The conflictual relations with travelers had the largest and most marked influence, it played a role in the area of sleep and cardiovascular and digestive problems. All of the 3 central job demands had an effect on sleep. The results point to a need for a multifaceted approach to research and intervention regarding the difficulties encountered by shift workers, from both the occupational medicine and the work design point of view. This conclusion seems particularly relevant for several professional sectors in which workers are confronted with both shift work and customer-focused jobs (police, prison guards, nurses, and the like).”

Parkes (1998) reported “a two-part study of human factors, shift work and alertness in the oil industry, with particular reference to control-room personnel working offshore.” Part I reported a questionnaire survey of 172 control-room operators, employed either on North Sea platforms or at onshore terminals, comparing the two work environments, and assessing their implications for employees’ physical and mental health, work satisfaction, and sleep patterns. “The offshore group showed significantly higher anxiety than those working onshore ... A higher incidence of sleep problems, marked dissatisfaction with shift schedules, and higher perceived workload also characterized offshore employees as compared with those onshore.” Part II reported a smaller-scale, more intensive, study of alertness among offshore operators. “The results demonstrated significant fluctuations in alertness and performance over the course of the two-week offshore work cycle; effects associated with different times within shifts were particularly apparent, but different phases of the offshore cycle (night shifts, shift-change, and day shifts) also showed significant patterns of results. The most marked and adverse effects occurred during the shift-change phase.”

Chaikittiporn, Kawakami, and Kogi (2001) examined “the working conditions of shift workers in a multinational [glass manufacturing] enterprise in Thailand” to identify practical support measures for improvements. “The direct observation study identified safety and health risks during the night work periods. The risks included insufficient lighting, height gaps on the floor, excessive exposure to heat, inappropriate workstations, and sleepiness and fatigue feelings among shift workers. Working consecutive double shifts and overtime work was often seen. An advisory meeting was held based on the study findings to assist managers and workers in improving their working conditions. A follow-up

visit six months later confirmed that the glass factory implemented several improvements to help night and shift workers. It was concluded that the direct observation methods associated with the time-budget study were helpful for identifying practical action points and strengthening workplace initiatives.”

Kogi (2004) examined “Voluntary industry-based guidelines on night and shift work for department stores and the chemical, automobile and electrical equipment industries.” “Both the guidelines and the plant maintenance work checkpoints were found to commonly cover multiple issues including work schedules and various job-related risks. This close link between shiftwork arrangements and risk management was important as shiftworkers in these industries considered teamwork and welfare services to be essential for managing risks associated with night and shift work. Four areas found suitable for participatory improvement by managers and workers were work schedules, ergonomic work tasks, work environment and training. The checklist designed to facilitate participatory change processes covered all these areas.”

Son et al. (2008) “investigated the effects of 12-hour shift work for five to seven consecutive days and overtime on the prevalence of severe sleepiness in the automobile industry in Korea.” “A total of 288 randomly selected male workers from two automobile factories were selected and investigated using questionnaires and sleep-wake diaries ... Factors related to working hours increased the risk for severe sleepiness at the end of the shift ... Long working hours and shift work had a significant interactive effect for severe sleepiness at work. Night shift workers who worked for 12 h or more a day were exposed to a risk of severe sleepiness that was 7.5 times greater than day shift workers who worked less than 11 h. Night shifts and long working hours were the main risk factors for severe sleepiness among automobile factory workers in Korea. Night shifts and long working hours have a high degree of interactive effects resulting in severe sleepiness at work.”

Ross (2009) noted that “Shift work is an integral part of many offshore jobs.” “Shift working has been an integral part of the offshore environment since the beginning of the industry, but it is only in the recent years that substantial effort has been directed towards the potential problems (or benefits) in this specific environment. It is clear that the offshore working community presents unique situations that need to be addressed specifically rather than managed as direct extensions of routine onshore shift work. Some unique features of the offshore workplace are identified and a number of possible areas for further research are highlighted.”

Ljoså and Lau (2009) studied a sample of 1,697 petroleum workers who worked onshore and offshore for a Norwegian oil and gas company.” “In general, only a few participants reported that their shift schedule affected their social and domestic/family life, and several participants had enough time to spend by themselves and with their partner, close family, friends, and children. Despite this general positive trend, differences were found for shift type and individual factors such as locus of control and coping strategies. Internal locus of control was associated positively with all the dependent variables. However, engaging problem-focused coping strategies were associated only slightly with the dependent variables, while disengaging emotion-focused coping strategies were negatively associated with the dependent variables.”

10. Police

Knauth et al. (1983) analyzed 120 police shift systems. As noted earlier, they included information on the “frequency distribution of the shift cycles, the duration of shifts, the start and end

of shifts, the maximal number of consecutive night shifts, as well as the frequency of different kinds of free weekends.”

Additionally, these investigators acquired diary data for 8 days from 120 policemen (Knauth et al., 1983). “The mean duration of sleep was reduced before morning shifts, between night shifts and after a morning shift that was followed by a night shift on the same day. The leisure time was limited in connection with afternoon shifts and between the combined morning and night shift. ... Rapidly rotated shift systems had more advantages referring to the total amount of night sleep than weekly rotated shift systems.”

Goslin (1986) surveyed U.S. Air Force security police personnel. “[N]ight and rotating shift workers reported significantly more work-related sleep problems than their day shift counterparts. Possibly related to the above conclusion, the perceived level of job effectiveness was significantly lower in night shift workers than day shift workers. Many day shift workers, however, reported that late night activities interfered with their job performance. Further, a significant number of night shift workers reported difficulty staying awake on the midnight shift. Clearly, however, the majority of these personnel believed they were more effective working a permanent as compared with a rotating shift schedule.”

Ottmann, Karvonen, Schmidt, Knauth, and Rutenfranz (1989) assessed “the subjective health status of day- and shift-working police officers.” The 2,659 shift-working and 1,303 day-working police officers were divided into four ten-year age classes. “Factor analysis revealed that all the symptoms included in the questionnaire could be grouped into six factors. The prevalence rates of complaints showed that four of these factors (autonomous symptoms, musculo-skeletal symptoms, disturbance of appetite and indigestion, respiratory infections) were influenced by the main effects of age and shift work. Across all age classes the age-related changes in prevalence rates were strengthened by shift-work. In the other two factors (nervous symptoms, gastro-intestinal symptoms) an additional interaction effect could be observed. While the prevalence rates of the day-workers increased with age, those of the shift-workers decreased in the oldest age class. This drop of prevalence rates may be attributed to the influence of selection processes.”

Garbarino et al. (2001) collected the Epsorth Sleepiness Score and a sleep disorders score from 1,280 policemen: 611 shiftworkers and 669 non-shiftworkers. “The ESS scores were not higher in shiftworkers than in non-shiftworkers, but the SD-score was found to be significantly influenced by shiftwork condition and seniority. The occurrence of sleep-related accidents was found to have been significantly increased for shiftworkers and related to the presence of indicators of sleep disorders. The sleepiness could be underestimated or even overcome by the influence of stressing conditions.”

Eriksen and Kecklund (2007) compared “a flexible shift system (based on self-determined work hours)” to “a rapidly rotating shift system, with frequently occurring quick returns.” The sample “included 533 randomly selected police officers, of which 26% were females. ... The results showed that the flexible shift system group did not differ with respect to sleep/wake complaints and subjective health. However, the flexible shift group obtained more sleep in connection with the shifts, probably because of longer rest time between shifts. Thus, they worked less quick returns and long work shifts. The association between work hour characteristics and sleep/wake complaints was weak in the flexible shift group. Instead, sleep/wake problems were mainly associated with the attitude to work hours.”

Kecklund, Eriksen, and Akerstedt (2008) examined the claim that “shift workers give priority to long series of days off and therefore prefer compressed work schedules at the expense of what is

optimal for long-term health.” The investigators evaluated the attitude to six new shift systems among a randomly selected sample of police officers. “The results showed that the most popular shift system was a rapidly, forward, rotating schedule with at least 16 h of rest between shifts, despite that it had fewer days off compared with some of the compressed shift systems.”

Barger et al. (2009) reviewed “the physiologic challenges inherent not only in traditional night or rotating shifts but also in extended-duration shifts and other nonstandard hours.” “The challenging schedules of those in particularly safety-sensitive professions such as police officers, firefighters, and health care providers are highlighted.”

See also the findings concerning metabolic syndrome among police officers in the Health--Hormones and Metabolism subsection, below (Violanti et al., 2009).

11. Rail

Foret and Lantin (1972) performed an EEG study of sleep periods of 10 French train drivers, recorded in real-life situations. The work schedule was very irregular: the distribution of working hours was almost a random function of the clock. The factor that played the most important part in determining the structure of a sleep period was the hour of the day. The data clearly underlined the great rigidity of the circadian rhythm.

Rutenfranz, Knauth, Hildebrandt, and Rohmert (1974; Rohmert, Hildebrandt, & Rutenfranz, 1974, 1975a) published three related reports in 1974-1975 on night and shift work in train drivers. A subsequent translation of Rohmert et al. (1975b) noted that “the present regulation of work for engine drivers of the German railroad demonstrates that discontinuity is the outstanding characteristic of their work schedule.” “All shifts are changed daily so that the driver is subject to an alternation in route, starting time, working time, and in the particular engine driven. For discussion of negative physiological and social effects of today’s shift work we analyzed the structure of the shift. Specific time tables of engines drivers in two German stations are discussed. Practical suggestions are given, aimed at avoiding negative effects of work schedules that put intolerable strain on engine drivers.”

Sherry (200) reviewed fatigue countermeasures programs instituted by various rail agencies and companies in the United States and Canada. These included Canadian Pacific, Canadian National, Conrail, Burlington Northern, CSX, Norfolk Southern, Union Pacific, North Little Rock, Amtrak, BNSF, and others. Sherry concluded that, in the several years there had been “considerable progress made in the area of napping and education. Most of the Class I railroads have adopted a napping policy. In addition, considerable effort has gone in to improving management and employee knowledge the effects and management of fatigue. There has been somewhat of a retreat from scheduling programs.”

Härmä, Sallinen, Ranta, Mutanen, and Müller (2002) reported a study “aimed at (1) studying the prevalence of severe sleepiness in shifts and (2) examining which shift and sleep-related factors were associated with the occurrence of severe sleepiness in an irregular shift system”. They used questionnaires and sleep-wake diaries to study 126 male train drivers and 104 railway traffic controllers. “The odds ratios showed that the risk for severe sleepiness was 6-14 times higher in the night shift and about twice as high in the morning shift compared with the day shift. ... Shift length increased the risk by 15% for each hour of the shift and main sleep period decreased the risk by 15% for each hour of the main sleep. The risk of severe sleepiness was not consistently related to the time-off period before the shifts.”

Using the same database, Sallinen et al. (2003) examined “the sleep-wake rhythm in shift combinations ending with the night or the morning shift in two irregular shift systems.” “The results showed that the sleep-wake rhythm was significantly affected by the shift combinations. The main sleep period before the first night shift shortened by about 2 h when the morning shift immediately preceded the night shift as compared with the combination containing at least 36 h of free time before the night shift (reference combination). The main sleep period before the night shift was most curtailed between two night shifts, on average by 2.9 and 3.5 h among the drivers and the controllers, respectively, as compared with the reference combination. Afternoon napping increased when the morning or the day shift immediately preceded the night shift, the odds being 4.35-4.84 in comparison with the reference combination. The main sleep period before the morning shift became 0.5 h shorter when the evening shift preceded the morning shift in comparison with the sleep period after a free day. The risk for dozing off during the shift was associated only with the shift length, increasing by 17 and 35% for each working hour in the morning and the night shift, respectively.”

Subsequently, Sallinen et al. (2005) used these data to examine the “occurrence of sleepiness in various shift combinations ending with a night or morning shift.” “The prevalence of severe sleepiness varied between 25% and 62% in the combinations ending with a night shift and between 12% and 27% in the combinations ending with a morning shift. The occurrence of sleepiness did not, however, systematically vary between the shift combinations in either case. An increased risk for sleepiness was associated with high sleep need and long shift duration in the night shift and with high sleep need, short main sleep period, long shift duration and an early shift starting time in the morning shift. ... The results suggest that the shift history of 24-36 h prior to the night and the morning shift is not strongly associated with the occurrence of sleepiness at work, but there are other factors, such as shift length and starting time and sleep need, that affect a risk for sleepiness at work.”

Viale and Gertler (2007) characterized the work/rest schedules and sleep patterns of U.S. railroad dispatchers and examined the relationship between these schedules and levels of alertness of the individuals working the schedules. “Overall, 39 percent of dispatchers get 6 or fewer hours of sleep while 29 percent of U.S. adults get this amount of sleep. Across all three shifts, dispatcher alertness on workdays peaked after arrival at work and then declined through the workday. The decline was greatest for those working third shift.”

In a follow-up study, Gertler and Nash (2006) explored approaches to establishing staffing levels and schedules for railroad dispatchers. “The present study had four objectives: (1) document current industry practices, (2) assess impact of current schedules on dispatcher fatigue, (3) develop methodology for establishing staffing levels, (4) develop alternative scheduling strategies. “Alternative scheduling strategies that can relieve these are the following: (A) Create a three crew self-relieving system, (B) Allow fixed weekday shift for senior dispatchers and rotate days off for remaining positions, (C) Assign relief dispatchers to a single shift and use extra board to cover unplanned vacancies on a single shift, (D) Convert weekends to two 12-hr shifts. All of these options have the potential to reduce fatigue and ease the burden for schedulers who must fill last-minute vacancies.”

Several of these and other occupational groups have been studied with respect to individual differences. These studies are described, below.

E. INDIVIDUAL DIFFERENCES

Yamasaki, Schwartz, Gerber, Warren, and Pickering (1998) evaluated the effects of shift work and race/ethnicity on the diurnal rhythm of blood pressure and urinary catecholamine excretion of healthy female nurses. The “results indicate that being African American and working evening or night shifts are independent predictors of nondipper status [$<10\%$ drop in systolic pressure during sleep]. Higher sleep blood pressure may contribute to the known adverse effects of shift work.”

Newey and Hood (2004) addressed levels of congruence between shift workers and their partners on experiences of shift work. The participants were 59 hospital shift-working nurses and their partners. “Results indicate that shift workers and their partners are congruent in their perceptions of the impact of shift work on the worker in all three lifestyle factors relating to tolerance across the three shift types. Shift workers experience more health/stress and social/family problems on the evening shift; this is related to their partners' increased sense of personal disruption. Similarly, when partners report the perceived impact of shift work on these same dimensions, it is associated with shift workers' heightened sense of personal disruption. Fewer sleep/fatigue and health/stress problems on the night shift are related to greater sleep flexibility, and evening types experience increased sleep/fatigue problems on the day shift. Social measures (particularly the personal disruption of the partner) rather than biological measures are the greatest predictors of shift workers' personal disruption.”

Costa (2004) noted that “The impact of shift and night work on health shows a high inter- and intra-individual variability, both in terms of kind of troubles and temporal occurrence, related to various intervening factors dealing with individual characteristics, lifestyles, work demands, company organization, family relations and social conditions.” “[D]ifferent criteria can be used to evaluate shiftworkers' health and well-being, starting from biological rhythms and ending in severe health disorders, passing through psychological strain, job dissatisfaction, family perturbation and social disadaptation, both in the short- and long-term. Consequently, it appears rather arbitrary to focus the problem of shiftworkers' health and tolerance only on specific aspects (e.g., individual characteristics), but a systemic approach appears more appropriate, able to match as many variables as possible, and aimed at defining which factors are the most relevant for those specific work and social conditions. This can support a more effective and profitable (for individuals, companies, and society) adoption of preventive and compensative measures, that must refer more to ‘countervalues’ rather than to ‘counterweights.’”

Takahashi et al. (2006) studied “the psychosocial factors at work that predict daytime sleepiness in a sample of day and shift workers.” The participants were 55 day workers and 57 shift workers who worked at a pulp and chemical factory and completed an annual questionnaire across three years regarding psychosocial factors at work. The investigators used the U.S. National Institute for Occupational Safety and Health Generic Job Stress Questionnaire. The results suggested “a potential predictive value of variance in workload for day workers as well as job satisfaction and depressive symptoms for shift workers with respect to daytime sleepiness.”

Van Dongen (2006) noted that there is increasing evidence that neurobiological factors play a role in tolerance for shift work, particularly the major processes involved in the regulation of sleep and wakefulness. He concluded that “It is important, therefore, to study the inter-individual differences in the regulation of sleep and wakefulness in the work environment so that cognitive impairment during shift work may be better anticipated and prevented.”

1. Adaptation and Tolerance

Reinberg et al. (1978) noted that the magnitude of the circadian acrophase (peak time) shift in response to a phase shift of socio-ecologic synchronizers (as in shift-work) varies from subject to subject. Data from two groups of selected shift-workers of 20 and 5 subjects, respectively, revealed a negative correlation: the smaller the amplitude of a circadian rhythm, the greater the shift in acrophase. This was true for oral temperature, peak expiratory flow, and urinary 17-OHCS, but not for grip strength, urinary K⁺ and Na⁺. "The small amplitude of certain circadian rhythms could be considered as an index of an individual's ability to phase-shift easily. However, chronobiological characteristics, other than the small circadian rhythm amplitude, remain to be identified, for both a better detection of one's ability to do shift-work and a better knowledge for practical applications."

Moog and Hildebrandt (1987) exposed healthy male subjects to various shift systems. "Adaptation and adjustment of the circadian systems were followed-up twice a week on so-called control days to reduce masking effects. With respect to the 24-hr minimum of rectal temperature and to the longest spontaneous sleep period on control days, the slower the shift system rotated and the later the individual circadian phase position was, the more subjects were able to follow the different shift systems. Subjects with stable phase shifts between the shift days always exhibited a phase shift of 1 hr per day."

Reinberg et al. (1989) studied 15 male subjects including 12 shift workers who were oil refinery operators. "The present study confirms for continuously recorded temperature and wrist activity, grip strength of both hands, heart rate and peak expiratory flow that intolerance of shift work is frequently associated with an internal desynchronization. However, this conclusion cannot be extended to circadian rhythms in self-rated drowsiness, fatigue and attention." "Since an internal desynchronization can be observed in tolerant shift workers having no complaint, it is likely that symptoms of intolerance are related to the subjects sensitivity to internal desynchronization rather than to the desynchronization itself."

Costa, Lievore, Casaletti, Gaffuri, and Folkard (1989) carried out a study "to evaluate whether shiftworkers showing different long-term tolerance to shiftwork differ in their circadian adjustments and/or in some behavioural characteristics." The subjects were three groups of eight workers, engaged on three shifts in a graphic plant. "The data obtained indicate that the characteristics of flexibility of sleeping habits, ability to overcome drowsiness, and lower manifest anxiety, are associated with better tolerance to shiftwork. These characteristics do not seem to influence the adjustment of the circadian rhythm of oral temperature passing from day to night-shifts and vice versa. Conversely, morningness appeared to be unrelated to long-term tolerance, but did influence circadian adjustments and sleep behaviour. Among the groups, the subjects with digestive disorders showed a greater phase shift and a reduction of the amplitude on night-work, suggesting a possible relationship also between the short-term circadian adjustment and the long-term tolerance to shiftwork."

Rosa et al. (1990) reviewed "a broad range of factors that, if controlled, might promote adaptation to nightwork, shiftwork, and extended workshifts." "Systematic study has begun in four of the areas reported here: work schedule design, napping, bright light stimulation, and drugs. Physical activity, ambient temperature, diet, and individual behaviors have been studied only superficially."

Siebenaler and McGovern (1991) provided a review in which they concluded that "Interventions should include a program that monitors workers' tolerance to shiftwork and provides information and

recommendations for employees to effectively manage a lifestyle that incorporates nighttime work schedules.”

Knauth and Härmä (1992) measured the subjective sleepiness and oral temperature of 147 female nurses at 2-hour intervals during a period with one morning shift and two consecutive night shifts, and the nurses filled out a questionnaire. “Two types of tolerance indices were constructed: The ‘health index’ was based on questions referring to general fatigue, gastrointestinal symptoms, and sleep disturbances, and the ‘sleepiness index’ on the actual subjective ratings of sleepiness. According to the health index, the group with good tolerance had a larger circadian amplitude of the oral temperature rhythm on the day of the morning shift than the group with poor tolerance. However, with regard to the sleepiness index, the corresponding difference between the groups with good or poor tolerance was not significant.”

Radošević-Vidacek et al. (1992) administered a battery of questionnaires to 604 rotating shift workers working in a fast rotating shift system. “[T]he shift workers’ characteristics accounted for a notable percentage (48%) of interindividual differences in sleep quality. However, there were fewer traits related to sleep duration than to sleep quality so that only a small percentage of interindividual differences in sleep duration could be explained (12-30%). Sleep quality proved to be a good indicator of night shift tolerance. The results concerning sleep duration indicated only sleep duration on the afternoon shift and days off, as well as average sleep duration in the complete shift cycle, to be relatively good indices of night shift tolerance.”

Motohashi (1992) monitored several circadian rhythms in seven shift-working ambulance personnel. “The incidence of internal desynchronization seemed to be higher in intolerant subjects, although the difference between tolerant and intolerant subjects did not reach a statistically significant level.” Härmä (1993) reviewed individual differences in the subjective health effects of shiftwork. “Individual factors related to shiftwork tolerance are discussed in two groups; first, the factors which affect primarily the circadian adjustment; and, second, the factors which mainly relate to the ability to sleep at unusual hours. The significance of circadian adjustment in shiftwork tolerance is outlined.”

Iskra-Golec (1993) attempted to determine “whether and to what extent circadian and personality characteristics contribute in determining attitude towards shiftwork” in female steel plant shift and dayworkers. “Amongst current shiftworkers, the best predictors of attitude towards shiftwork were flexibility of sleeping habits and the ability to overcome drowsiness. Amongst former shiftworkers attitude was determined primarily by reactivity, but in the dayworkers without shiftwork experience no predictors of the attitude were found.”

Menna-Barreto, Benedito-Silva, Moreno, Fischer, and Marques (1993) examined “the anticipatory response of the sleep onset time preceding work in order to reveal the strategy used by workers submitted to those shift systems including night work.” “Night workers go to bed once a day, whereas shiftworkers prefer to allocate their sleep onsets to two different periods of the day. For both cases, the more well-adapted an individual is, ... the more regular will be the choice of sleep onset times.”

Vidacek et al. (1993) examined “the predictive relationships between the amplitude, phase, and mesor of 24 h rhythms obtained before exposure to shiftwork, and subsequent indices of tolerance measured after one and three years of shiftwork.” “Workers who had a higher mesor of positive moods, and a lower mesor of negative moods and fatigue, before entering shiftwork tended to tolerate shiftwork better. Further, those whose heart rate rhythm showed an earlier acrophase had better

subsequent sleep quality scores, while those with a smaller amplitude of their temperature, negative mood and fatigue rhythms showed better night-shift tolerance.”

Quera-Salva et al. (1997) “studied the performance and adaptability of 40 nurses, 20 on permanent day shift and 20 on permanent night shift with fast rotation of work and days off.” “Despite similar gender, age, social conditions, and light exposure levels, a minority of the nurses studied possessed the physiological ability to adapt to a fast-shifting sleep-wake schedule of more than 8 hours and were able to perform appropriately in both conditions. This shift was associated with a change in the acrophase of 6-sulfatoxy-melatonin.”

Costa (1997, 1999) reviewed the shiftwork research literature, noting that “A high inter-individual variability is recorded in both short-term adjustment and long-term tolerance, being connected to individual factors as well as to work organization (shift schedules in particular) and social conditions.” Nachreiner (1998) provided another review, finding that “individual differences show only some low and inconsistent concurrent co-variation with shiftwork tolerance, and no predictive power for these measures has been found.” Nachreiner continued, “It is thus not possible to predict future shiftwork tolerance from individual differences. Social conditions are also related to shiftwork tolerance, although again predictive power has not been demonstrated.”

Two years later, Åkerstedt (2000) published a “limited review,” suggesting that personality and circadian amplitude, and gender seemed to “have little to do with tolerance of shift work.” Age and diurnal type may affect tolerance, but “the two seem closely related.” He suspected that the “major determinants of shift work tolerance” probably had more to do with “ways of coping with irregular work hours,” including the way an individual organizes their behavior to promote sleep and avoid morning light after night work, and their need for sleep. He suspected that the “highly tolerant single night shift worker would be older, have a low need for sleep, have a high sleep quality, be in good physical shape, and plan sleep strategically (using naps). If several night shifts occur in sequence, younger individuals may have an advantage.”

That year also saw the publication of the proceedings of a Workshop sponsored by the NATO Human Factors and Medicine Panel and held at the Scuola Navale Militare Francesco Morosini in Venice, Italy, from 3-4 June 1999 (NATO, 2000). “There is a growing body of knowledge pointing to the existence of important individual psychophysiological differences that may enable some individuals to better adapt to irregular rest-work rhythms. Furthermore, selected categories of drugs may be employed in operational conditions. The purpose of this Workshop was to address both the individual difference implications during irregular sleep-wake regimens and the state of the art in the pharmacological management of sleep-wake rhythms.”

Ahasan, Lewko, Campbell, and Salmoni (2001) reviewed the literature and provided suggestions “to enhance workers’ adaptation to night shift and synchronization process.”

Takahashi et al. (2005) examined “the relationship between perceived adaptation to shift work and shift-related problems” among 608 male operators at nuclear power plants. “The good adaptation group showed better outcomes than the poor adaptation group in terms of fit to job content, chronic fatigue, daytime sleep before night shifts, social and family disruption, SHLOC, psychological health, and alertness during night shifts. Operators who reported good adaptation also took a more frequent, longer nap and more cigarettes during night shifts.”

Boivin, Tremblay, and James (2007) noted that “Individuals vary greatly in their capacity to adjust to atypical work schedules and their tolerance to circadian misalignment.” “Predisposing

individual and domestic factors have been identified, such as increasing age, being a single woman in charge of children, and split sleep patterns, all of which can affect the ability to adjust to atypical schedules. However, prior studies indicate that predisposing individual and social determinants are generally poor predictors of shift work tolerance in a given individual. In this manuscript, we review several countermeasures to improve adaptation to shift work.”

Van Dongen (2006) presented evidence that inter-individual differences in neurobiological factors, particularly the major processes involved in the regulation of sleep and wakefulness, play important roles in tolerance for shift work. West et al. (2007) provided a similar argument in the context of the attrition rate of New Graduate Nurses.

Burch et al. (2009) used two validated questionnaires (the Standard Shiftwork Index and the Pressure Management Indicator) to identify factors predicting shiftwork adaptation. “Night and relief/combined shiftworkers reported a greater ability to accommodate irregular schedules and disrupted sleep, but were also more likely to report work-related impacts than day workers. Permanent night workers generally reported poorer health, more absenteeism and less job satisfaction than day workers. Factors associated with optimal work performance or schedule contentment among shiftworkers included adequate sleep, evening circadian preference, increased age and organizational satisfaction. Reduced work performance or schedule discontent was associated with sleep/wake difficulties and poor health.”

2. Age

Åkerstedt (1990) noted that “The psychophysiology of shift work is mainly related to circadian rhythmicity and sleep-wake phenomena.” “Older age and ‘morningness’ personality are related to higher than average problems in adjusting.” However, Härmä, Knauth, Ilmarinen, and Ollila (1990) studied “The relation of age to the adjustment of the circadian rhythms of oral temperature and sleepiness in shift work,” using 145 healthy female nurses as subjects. The results failed to corroborate that physiological adjustment to night work would be influenced by age. The oldest age group was 40-49 years.

Ogińska, Pokorski, and Ogiński (1993) compared “two matched-for-age-and-occupation groups of men and women, each of 83 [crane-operators], ... in a Polish steel plant.” The subjects worked a “forward-rotated, three-shift, four-team shift system.” “Women experienced more sleep disturbances than men and suffered more frequently from drowsiness during work, especially when working the morning shift. The ratings of subjective health were lower in women ... However, after passing the ‘critical decade’ of 40-50 years their subjective health generally improved, whereas in males one observed the consequent deterioration of health with advancing age. Women more often complained about their health and went to see the doctor, but on the other hand, they did not tend to quit shiftwork as often as did their male counterparts.”

Tepas, Duchon, and Gersten (1993) reviewed literature concerning “a statistically significant interaction among age, gender, and shift for the workday sleep length of workers on permanent day, afternoon/evening, and night shifts.” “The results support the assumption that most night shiftworkers are at risk even though they often give the appearance of being able to tolerate nocturnal work hours. However, it is not yet clear how age and gender are related to the social, circadian, and environmental factors that influence the sleep length of shiftworkers.”

Härmä, Hakola, Akerstedt, and Laitinen (1994) conducted a study designed “to examine the effects of age on sleep and the circadian rhythms during consecutive night shifts.” They used two 7-person groups of letter sorters, ages 19-29 and 53-59 years. They concluded that “Aging decreases the ability to recover after several, but not after the first night shift.”

In a laboratory study, Della Rocco and Cruz (1995) investigated sleep patterns during the FAA Air Traffic Control Specialist rotating shift, the 2-2-1 rotation from two afternoon shifts to two mornings and, finally, to a midnight shift. They used four groups of five male subjects between the ages of 30 to 35 and 50 to 55 years. “Average sleep durations decreased over the week of the 2-2-1 from an average of 7.6 hours, on Sunday night prior to the first afternoon shift, to 3.0 hours just prior to the midnight shift. ... No difference was found between age groups.”

“Significant [cognitive] performance decrements were observed primarily on the night shift for both age groups. The older group demonstrated decrements in accuracy of recall on the code lock task following both rapid rotations during the 2-2-1 schedule” (Della Rocco & Cruz, 1996).

Rosa, Härmä, Pulli, Mulder, and Näzman (1996) evaluated “a new work schedule at a Finnish steel mill with special attention to effects on older workers. The schedule was designed to improve sleep before the morning shift, and alertness during the morning shift, by delaying shift start and end times.” “The one hour delay in shift starting times improved sleep before the morning shift, and improved waking fatigue, sleepiness, and performance during the morning shift. Evening and night shift sleep and fatigue or sleepiness, however, were affected negatively by the new work schedule, but the results for those shifts were less consistent across the various measures. Despite the improvements, most workers were not satisfied with the new schedule because of social concerns. Few interactions of age with the new work schedule were found, suggesting that the effects of the work schedule were uniform across age groups.”

Duffy et al. (1998) investigated “The contribution of the circadian timing system to the age-related advance of sleep-wake timing.” The results led them to “hypothesize that under entrained conditions, these age-related changes in the relationship between circadian phase and wake time are likely associated with self-selected light exposure at an earlier circadian phase. This earlier exposure to light could account for the earlier clock hour to which the endogenous circadian pacemaker is entrained in older people and thereby further increase their propensity to awaken at an even earlier time.”

Marquié and Foret (1999) questioned a sample of 3,236 wage earners composed of 32-, 42-, 52-, and 62-year-old subjects. “Age resulted in a continuously increasing frequency of sleep disturbances and hypnotic use, except for difficulty getting back to sleep and early awakening, which peaked at 52 years and then decreased at 62 years, thus suggesting a ‘retirement effect.’ Current and past shiftworkers reported more problems with falling asleep and early awakening than subjects who had never worked on shifts. ... There were no clear effects of the length or recency of shiftwork experience. ... Females had higher complaint rates at every age. There was little interaction between age and sex, but women were affected more by shiftwork as they got older, particularly as to hypnotic consumption.”

Reid and Dawson (2001) simulated a 12-hour shift rotation and measured differences in performance between older and younger subjects. “Performance for the older subjects was consistently lower than for the younger subjects. There was a significant difference in performance across the shift between older and younger subjects. There was a significant change in performance

across the shifts in the older subjects, such that performance significantly increased across the day shifts and decreased across the night shifts. By contrast, the younger subjects were able to maintain performance across both day shifts and the second night shift.”

Härmä and Ilmarin (1999) summarized the current knowledge on the relationship between shift work, aging, and health and outlines practical countermeasures and research needs to improve the health and well-being of aging shift workers. Hakola and Härmä (2001) explored the effects of a change in the speed and direction of shift rotation on the sleep and wakefulness of six younger and six older workers. “The change in schedule influenced sleep differently in the two age-groups. Both the subjective and objective quality of sleep improved among the older workers. The results indicate that a fast forward rotating shift schedule is more suitable for older workers than a slower backward rotating system.” Härmä and Kandolin (2001) noted in a review that “The evidence of good age-specific solutions in working hours is limited, but the few published intervention studies support the use of individual flexibility, rapid forward rotating shift systems, and earlier shift start-end times in three-shift work”.

Smith and Mason (2001a) examined the effects of a change in *rota* upon sleepiness and fatigue, and potential age-related issues among 102 police officers. “Older officers tended to report higher fatigue and sleepiness, and higher caffeine intake than the younger shiftworkers irrespective of *rota* or shift.” The same investigators examined age related effects of shiftwork among 306 police officers who had worked a new *rota* for approximately 6 months (Smith & Mason, 2001b). Three age groups were compared: 20-32.9, 33-39.9, and 40+ years. “Older shiftworkers reported significantly higher morningness and lower sleep need than the younger officers. ... It was also evident that the older group tended to resort to greater caffeine intake on all shifts.”

Bonnefond et al. (2006) studied work shift related interactions of age with sleep-wakefulness, performance, and social life. “Although the shift type influenced the sleep, subjective sleepiness, performance, and social life, age was distinctly related only to shift-related changes in the amount of sleep, subjective sleepiness, and psychomotor vigilance. ... Although subjective sleepiness was greatest among the youngest (25-34 years) age group during the morning and the night shifts, the increase of performance lapses was higher among the middle-aged (35-49 years) and senior (50-58 years) groups during the night shifts compared to the youngest age group. According to the questionnaire, older shiftworkers also tended to perceive more frequently that subjective sleepiness decreases their work performance during the morning and night shifts.”

Folkard (2008) reviewed the literature relating safety to features of shift systems, then considered the general effect of age on occupational injury rates, and examined existing evidence of the combined effects of shift work and age on performance capabilities. “The results of the literature review indicate that when the *a priori* risk is constant, there is reasonably clear evidence that injury rates are higher at night, and that they increase over successive night shifts more rapidly than over successive day shifts. Further, although occupational injuries are less frequent in older workers, those that do occur tend to be more serious. Finally, there is some suggestive evidence from studies of objectively measured performance capabilities that older workers may be less able to both maintain their performance over the course of a night shift and cope with longer spans of successive night shifts.”

3. Gender

Vidacek (1981) studied the productivity of women-workers in a company manufacturing electronic equipment. Härmä, Ilmarinen, and Knauth (1988) examined some aspects of shiftwork tolerance in 128 female nurses, including maximal oxygen consumption (VO₂max), muscle strength and physical activity. "Neuroticism was the most powerful negative factor connected to higher fatigue and various symptoms of the subjects. High VO₂max and good muscle strength were, on the other hand, the most important positive factors connected to lower fatigue and musculoskeletal symptoms and better sleep quality of the subjects. In different shifts, fatigue, sleep length and quality were influenced most by morningness."

Chan et al. (1993) studied health complaints, blood pressure, sleep and sickness absence experience in 308 female electronics workers employed for at least one year on 12-hour shifts. The results indicated no serious health problems among workers on 12 h shift for over a year. Chan (1994) reviewed the literature with respect to shiftwork in Singapore. "So far, our own studies of female electronics workers on 8-hour as well as 12-hour shift schedules indicate no serious long-term health effects."

Hakola, Härmä, and Laitinen (1996) examined the adjustment of sleep-wakefulness and other circadian rhythms during consecutive night shifts in the laboratory to study the effect of gender on the adjustment to night work. "Sleepiness decreased during the consecutive night shifts but did not reach the level of the day shift during the three nights. The sleepiness of the women decreased more than that of the men, the difference being significant during the second and third night shifts."

Rotenberg, Portela, Marcondes, Moreno, and Nascimento (2001) conducted a field study at a factory employing men and women on the night shift. "Quantitative sleep analysis showed more severe effects of night work on women, especially those with children. Such sleep patterns were associated with different expectations among men and women, revealing gender issues that are essential for understanding the reality of individuals who work odd hours."

Hirose (2005) reviewed research findings on sleep and health for shift workers at a bakery and a dish factory with the aim of providing information on health protection with improved sleep. "Our medical examinations revealed that rises in blood pressure (BP) were frequently observed in male bakery workers on the fixed night shift. They took a two-hour nap from 1:00 to 3:00 during the night shifts according to our advice. As a result, their diastolic BP significantly decreased in subsequent years. Women working shifts before 3:00 at a dish factory seemed to show more sleep disturbance, higher daytime sleepiness, and more fatigue than those working shifts from 3:00. Total sleep hours taken during the daytime was similar between two groups. Among the dish factory workers who switched to midnight or night shifts, 70% reported slow recovery from fatigue and 30% felt deteriorated health. These women also reported increased efforts to obtain a deep sleep, probably making up for shortened sleep."

Kubo et al. (2008) evaluated "the relationship between anxiety expressed about starting three-shift work and background characteristics among 38 female workers who were being assigned to three-shift work for the first time." "[W]e found a marginally statistically significant trend association between frequent breakfast consumption and anxiety about starting three-shift work. Anxiety was also high among subjects with sleep disorders, especially those suffering from subjective sleep insufficiency."

Rotenberg et al. (2008) examined the association between working hours and work ability in a cross-sectional study of 156 male and 1,092 female nurses. “Logistic regression analysis showed a significant association between total work load and inadequate work ability index (WAI) for females only. Females reported a higher proportion of inadequate WAI, fewer professional work hours but longer domestic work hours. There were no significant differences in total work load by gender. The combination of professional and domestic work hours in females seemed to best explain their lower work ability.”

Also, see Ogińska et al. (1993) and Tepas et al. (1993) and Marquié and Foret (1999) in the Age subsection, above; see Kario et al. (2002) in the Health-Cardiovascular subsection, below; see Ogińska et al. (1990) in the Lark-Owl subsection, below; and see Schernhammer et al. (2004) in the Countermeasures-Melatonin subsection, below.

4. Lark-Owl

Åkerstedt (1990) noted that “The psychophysiology of shift work is mainly related to circadian rhythmicity and sleep-wake phenomena.” “Older age and ‘morningness’ personality are related to higher than average problems in adjusting.”

Ogińska et al. (1990) described a comparative study of chrono-types with regard to the subjective health, sleep disorders and disturbances, attitudes towards shiftwork and physical fitness. “In spite of differences in the bedtime and awaking time, representatives of morning and evening type did not differ when considering the amount of sleep. Both groups slept about one hour less than subjectively required. The analysis of sleep disorders (during days with various shifts and days off) showed that their configuration was different in compared groups. Morning types more often woke before proper time and suffered from frequent mid-sleep awakenings. They had also more difficulties in falling asleep and felt tired after awakening when working night shift. Evening types reported more often difficulties in awakening (independently on work shift) and complained low well-being or tiredness after awakening when working morning or afternoon shift and during days off. The percentage of morning types reporting various sleep disturbances of external (noise, daylight) or internal (hunger, nervousness) origin was 13 to 74%. The corresponding figures for evening types were 4 to 52%. ... It was found that morning individuals significantly more frequently reported fevers and sub-febrile states, itching in heart region, pains or tightness in heart region when nervous and musculoskeletal pains. No significant differences in gastrointestinal complaints were found. Analysis of typical circulatory, respiratory and musculoskeletal syndromes revealed the lower frequency of circulatory and musculoskeletal complaints and more respiratory symptoms in evening types. This latter could be considered as the result of prevalence of smokers in this group. The prediction of maximal oxygen uptake ... showed significantly higher values in evening types. Taking into account that the result of this method is based on the heart rate response to submaximal load—it is highly probable that the difference observed is due to chrono-type related difference in phase of circadian rhythm of heart rate reaction to the load applied on the same time of the day. Both studied groups differed significantly as to the percentage of persons approving the work in shifts.”

Steele et al. (1997) determined the morningness-eveningness (ME) distribution of emergency medicine (EM) residents. “ME scores ranged from 24 to 76, with a median score of 49 (interquartile range 44, 56). The scores were distributed differently from those of the normal population, being skewed toward eveningness. There was a correlation between resident age and ME score, with older

residents being more morning-oriented. Males were more morning-oriented than females, and respondents with children living at home also were significantly more morning-oriented.”

Smith, Norman, and Folkard (2001) examined shiftwork locus of control (SHLOC), measures of circadian type and shiftwork-related outcome measures in 100 shiftworkers on two occasions separated by seven months. “The results of multivariate regression analysis showed the SHLOC scale to be predictive of the experience of shiftwork-related sleep and social-life problems while the circadian type measures were predictive of alertness at 7 months.”

Natale, Martoni, and Cicogna (2003) investigated the effects of circadian typology on sleep-wake behavior in 18 air traffic controllers, using wrist actigraphy in 18 air traffic controllers, nine morning types and nine evening types. “Evening types presented more flexible sleep habits and slept significantly less than morning types. Regardless of circadian typology, the morning shift tended to reduce the amount of sleep whereas night shift produced a decrease in daily activity.”

Also, see Matsumoto et al. (1996) in the Nurse subsection, above.

5. Locus of Control

Smith and Mason (2001c) reported “one of a series of studies aimed at examining the relationship between internal locus of control (internality) and commonly reported outcomes of exposure to shiftworking.” They used the Shiftwork Locus of Control (SHLOC) scale and other outcome measures, and controlled for age, shiftwork experience and years of service effects. “[H]igher internality was associated with significantly lower levels of shiftwork problems, especially when compared to the low internality group.”

Smith et al. (2001) followed with a similar study conducted on 100 shiftworkers on two occasions separated by seven months. The SHLOC scale was “predictive of the experience of shiftwork-related sleep and social-life problems while the circadian type measures were predictive of alertness at 7 months.”

Smith et al. (2005) attempted to “identify individual differences correlates of sleep and fatigue-related shiftwork outcomes and examine their potential relative causal impact.” They studied power company shiftworkers. “Shiftwork-specific internality showed the most systematic significant causal relationships with sleep and fatigue outcomes. While not having as strong a direct causal influence on sleep and fatigue outcomes as internality, the other predictors did show more significant causal effects upon sleep-related behaviours than did internality. Behavioural variables made little contribution to the total causal effects of the predictors on the outcome variables.”

F. FATIGUE COUNTERMEASURES

Richardson and Tate (2000) provided an excellent introduction to the need for some types of fatigue countermeasures in response to the effects of shiftwork.

The mammalian circadian oscillator, located in the suprachiasmatic nuclei of the anterior hypothalamus, serves as the principal source of rhythmic temporal information for virtually all physiologic processes in the organism, including the alternating expression of sleep and wakefulness. Recent studies, in both animal models and human subjects, have demonstrated the important modulation of sleep and wakefulness mediated by the circadian clock. Independent of other factors, notably prior sleep-wake

history, the circadian clock potentiates wakefulness (and alertness) at one phase of the diurnal cycle, while facilitating sleep and its attendant processes at the opposite phase. The adaptive advantage of synchronizing sleep-wake behaviors with the daily changes in the external environment is clear. But in a modern world where the constraints of environmental time are less and less important, the circadian clock still imposes rigid boundaries on the timing of sleep and alert wakefulness that are increasingly perceived as limitations on human performance. This conflict underlies the sleep "disorders" of jet lag and shiftwork sleep disruption, problems that are not really diseases at all, but instead reflect normal function of circadian timing in the context of extraordinary demands on sleep-wake scheduling. Whatever their proper classification, both jet lag and shiftwork insomnia represent important societal problems deserving of public health and medical attention. ... In contrast to jet lag, shiftwork produces chronic sleep disruption lasting for the duration of shiftwork exposure. For while individual differences in the ability to adjust to a nocturnal work schedule clearly exist, recent studies suggest that few if any night workers regularly experience restful and restorative day sleep equivalent to that considered normal at night. This chronic sleep limitation is associated with significant increases in a number of consequent problems including sleepiness-related accidents, social disruption, and psychiatric disturbances. ... The most important aspect of human circadian physiology that limits adaptation to the extreme schedules inherent in shiftwork and jet travel is the primacy of light among entraining signals, or *Zeitgebers*. Exposure to sunlight for night shiftworkers, or for jet travelers at their destination, results in maintenance (or resetting) of the clock to environmental time. This response can be prevented or overridden with extraordinary avoidance of sunlight or with provision of artificial light of sufficient duration and intensity to negate the sunlight signal, an approach shown to be effective in the treatment of shiftwork sleep disruption. Practical issues sharply limit the application of artificial lighting to all shiftwork settings, however, and the role for a pharmacological chronobiotic agent capable of accomplishing the same end is potentially very large (Copinschi et al., 1995; Jamieson et al., 1998) (Richardson and Tate, 2000, p. S77).

Van Reeth (1998) noted that "Shift work operations are thus associated with serious healthy and social problems for the workers." "Various interventions can counteract circadian desynchronization, sleep disturbances, and social disruption associated with shift work: changes in work schedules, sleeping and napping strategies, use of appropriately timed exposure to bright light, experimental drug treatments, or exercise." Monk (2000) provided "a review of how the increasing numbers of people working abnormal hours (referred to as "shift workers") can best be helped by the science of chronobiology." Moeno and Louzada (2004) presented "some recent chronobiological findings related to shift and night worker adaptation." "First, some key chronobiological concepts concerning the human species are presented. The authors then discuss the possible impacts of work schedules on shift workers' and night workers' health. Finally, countermeasures that might allow adjusting the workers' biological rhythm to shift and night work are discussed."

1. Light

Aschoff et al. (1975) described the state of knowledge in 1975 concerning circadian time cues and physiology. "To describe an abrupt shift of the *Zeitgeber* sufficiently, it is necessary to indicate whether the phase has been advanced or delayed, for how many hours it has been shifted, and what part of the *Zeitgeber* has been lengthened or shortened respectively. The entrained circadian system usually follows a shift of the *Zeitgeber* in the same direction and by an equal amount. However, there can be exceptions to both of these rules."

Comperatore (1993) described the problems associated with shift lag in the Army aviation community. The review focuses on "the role of environmental lighting, and specifically identifies methods of preventing sleep loss and fatigue during the transition from daytime to nighttime duty hours."

Hayes et al. (1994) developed procedures for using intense light to phase-shift circadian rhythms and improve performance, sleep, and wellbeing during shiftwork by NASA payload specialists. Campbell (1994) investigated the effects of bright light interventions on schedule adaptation to night work in 26 middle aged individuals in a simulated shift work study. Stewart, B. Hayes, and Eastman (1995) designed and tested light-treatment protocols for NASA personnel who worked on shifted schedules during two Space Shuttle missions. "During the prelaunch week, treatment subjects self-administered light of approximately 10,000 lux at times of day that phase-delay circadian rhythms. Treatment continued during the missions and for several days afterward. ... Treatment subjects reported better sleep, performance, and physical and emotional well-being than control subjects and rated the treatment as highly effective for promoting adjustment to their work schedules."

Eastman et al. (1995) reviewed "studies in which the sleep schedule is shifted several hours, as in shift work, and bright light is used to try to phase shift circadian rhythms." "So far, the only studies on the use of bright light for real shift workers have been conducted at National Aeronautics and Space Administration (NASA). In general, the bright light studies support the idea that the control of light and dark can be used to overcome many of the problems of shift work."

Bougrine, Mollard, Ignazi, and Coblentz (1995) examined "the stability of bright light circadian readjustment during two consecutive dim light night-work periods and circadian synchronization during the recovery after a night-shift period." The results suggested that "three cycles of bright light [2500-3000 lux] are sufficient to induce a significant phase delay and that this delay remained stable when night-work proceeded under dim light."

Samel and Gander (1995) focused on work-rest schedules during long duration space missions. "Four male subjects were exposed to two sessions of 11 d of simulated microgravity (6 degrees head down tilt bedrest) with 6-hour extensions of the wake period on 2 days (12-hour phase delay). In a blind crossover design, subjects were exposed to bright light (>3500 lux) for 5 h on each of the 2 shift days and the following day." The results confirmed "the disruptive effects of wake-rest schedule shifts on sleep and circadian rhythms. Contrary to our initial hypothesis, 5-hour exposures to bright light finishing at the time of the circadian temperature minimum were not more effective at accelerating adjustment to a 12-hour schedule delay than exposures coinciding with the temperature maximum. We conclude that, while bright light may accelerate adjustment to work-rest schedule delays, any such effect seems to be largely independent from the timing of the light exposure."

Mitchell, Hoese, Liu, Fogg, and Eastman (1997) conducted a simulated night shift field study to compare "high-intensity ('bright') light exposures [about 5,000 lux] designed to either facilitate or

conflict with adaptation to a 9-hour phase shift of the sleep/dark schedule.” “The bright light was timed according to the light phase-response curve (PRC) to delay or advance rhythms; it was timed to occur either before or after the baseline body temperature minimum, which served as an estimate of the PRC crossover point between delays and advances. ... These results show that it is important to time bright light appropriately to achieve circadian adaptation to the night shift and that individual differences play an important role in the ability of the circadian system to phase shift.”

Bjorvatn and Holsten (1997) discussed how light influences and regulates the circadian rhythm. Kelly et al. (1997) “examined the effects of two interventions to adapt circadian rhythms, sleep and performance to a 10-hour phase delay of the work-rest cycle.” “Bright light accelerated phase delay of the circadian melatonin rhythms after the work-rest schedule shift. Further, subjects who received bright light had greater total sleep time (TST) and improved sleep continuity.”

Martin and Eastman (1998) assessed the effects of “nocturnal light intensity [5700 lux] on circadian adaptation to simulated night work.” The subjects wore dark sunglasses while outdoors during daylight. The investigators concluded that “Extremely ‘bright’ light may not be necessary for circadian adaptation in shift work situations similar to our study protocol (e.g., regular daytime sleep/dark periods, sunglasses).”

Eastman and Martin (1999) reviewed “field studies of simulated night work in which shifted light-dark cycles were constructed with artificial bright or medium-intensity light to produce circadian adaptation.” “By using these studies we describe fundamental principles of human circadian rhythms relevant to producing circadian adaptation to night shift work at a level designed for the reader with only a basic knowledge of circadian rhythms. These principles should enable the reader to start designing work/sleep-light/dark schedules for producing circadian adaptation in night shift workers. ... Finally, we discuss phase-response curves to light and clarify common misconceptions about the production of circadian rhythm phase shifts.”

Horowitz and Tanigawa (2002) reviewed “a number of laboratory studies designed to treat circadian maladaptation to night work by shifting the circadian clock with light, exercise, or melatonin.” “There is substantial evidence that bright light treatments can successfully overcome the circadian misalignments associated with night work. The evidence for the efficacy of non-photoc synchronizers such as exercise and exogenous melatonin is equivocal.” Burgess, Sharkey, and Eastman (2002) discussed “the efficacy of appropriately timed bright light exposure (natural and artificial) and exogenous melatonin administration for producing circadian adaptation to night work”. They concluded the review by “discussing the impact of individual differences on possible circadian interventions and issues associated with the use of bright light interventions in the field.”

Boivin and James (2002) “tested the efficacy of an intervention designed to promote circadian adaptation to night-shift work” on 15 nurses working permanent nights. After vacation of day-only work, the nurses were studied in the laboratory on a constant routine; then, they returned to night work with or without bright light therapy and work and light-protection goggles in the morning. “These results support the efficacy of a practical intervention for promoting circadian adaptation to night-shift work under field conditions.” Boivin and James (2005) also reviewed the literature and discussed “the usefulness of light treatment as a countermeasure for maladaptation to atypical work schedules.”

Crowley, Lee, Tseng, Fogg, and Eastman (2003) used “various combinations of interventions to phase-delay circadian rhythms to correct their misalignment with night work and day sleep.”

“Participants wore sunglasses with normal or dark lenses (transmission 15% or 2%) when outside during the day. Participants took placebo or melatonin (1.8 mg sustained release) before daytime sleep. During the night shifts, participants were exposed to a moving (delaying) pattern of intermittent bright light (approximately 5000 lux, 20 min on, 40 min off, 4-5 light pulses/night) or remained in dim light (approximately 150 lux). There were 6 intervention groups ranging from the least complex (normal sunglasses) to the most complex (dark sunglasses + bright light + melatonin). ... The authors recommend the combination of intermittent bright light during the night shift, sunglasses (as dark as possible) during the commute home, and a regular, early daytime dark/sleep period if the goal is complete circadian adaptation to night-shift work.”

Santhi et al. (2005) compared the ability of two sleep/dark schedules to shift circadian phase in a simulated shift-work study. Their results indicated that “scheduled sleep/darkness can aid in adaptation to night shift work by inducing both advance and delay phase shifts, depending on the timing of the sleep schedule, although the size of the phase shifts are not sufficient to produce complete adaptation to the night shift.”

Revell et al. (2006) set out “to determine whether phase advances induced by morning intermittent bright light and a gradually advancing sleep schedule could be increased with afternoon melatonin.” “Afternoon melatonin, morning intermittent bright light, and a gradually advancing sleep schedule advanced circadian rhythms almost 1 h/d and thus produced very little circadian misalignment.”

Paul et al. (2007) “compared four phototherapeutic devices for efficacy in effecting circadian phase delays.” “All phototherapy devices produced melatonin suppression and significant phase delays. Sleepiness was significantly decreased with the light tower, the light visor, and the Litebook. Task performance was only slightly improved with phototherapy. The LED spectacles and light visor caused greater subjective performance impairment, more difficulty viewing the computer monitor and reading printed text than the light tower or the Litebook. The light visor, the Litebook, and the LED spectacles caused more eye discomfort than the light tower. The light tower was the best device, producing melatonin suppression and circadian phase change while relatively free of side effects.”

Thorne et al. (2008) investigated “circadian phase, sleep, and light exposure in subjects working 18:00-06:00 h and 19:00-07:00 h schedules during summer.” “In these offshore conditions in summer, the earlier shift start and end time appears to favor daytime sleep.”

Gooley (2008) examined “the physiological basis for bright light therapy” and discussed “the application of light in the treatment of circadian rhythm sleep disorders including advanced and delayed sleep-phase disorder, free-running disorder (non-entrained type), shiftwork disorder and jet lag disorder.” Gooley (2008) reviewed “the laboratory and field studies which have established bright light therapy as an effective treatment for sleep-wake and circadian misalignment, and we also provide guidelines for the appropriate timing and safe use of bright light therapy” (p.-----?).

Lee, Smith, and Eastman (2006) conducted a set of studies with the goal of producing “a compromise phase position in which individuals working night shifts delay their circadian clocks to a position that is more compatible with nighttime work and daytime sleep yet is not incompatible with late nighttime sleep on days off.” In the first study, the subjects received “five 15 min intermittent bright light pulses (approximately 3500 lux; approximately 1100 microW/cm²) once per hour during the night shifts, wear sunglasses that attenuate all visible wavelengths—especially short wavelengths (‘blue-blockers’)—while traveling home after the shifts, and sleep in the dark (08:30-15:30 h) after

each night shift.” “Two night shifts with a practical pattern of intermittent bright light, the wearing of sunglasses on the way home from night shifts, and a regular sleep period early in the daytime, phase delayed the circadian clock toward the desired compromise phase position for permanent night shift workers.”

In a second study, Smith, Cullnan, and Eastman (2008) attempted to “delay the dim light melatonin onset (DLMO) from its baseline phase of approximately 21:00 to our target of approximately 3:00.” “Two experimental groups received intermittent bright light pulses during night shifts (total durations of 75 and 120 min per night shift), wore dark sunglasses when outside, slept in dark bedrooms at scheduled times after night shifts and on days off, and received outdoor light exposure upon awakening from sleep. ... the DLMO of the experimental groups was approximately 00:00-1:00, not quite at the target of 3:00, but in a good position to reach the target after subsequent night shifts with bright light.”

In a third study by Smith and Eastman (2008), “subjects received five, 15 minute bright light pulses from light boxes during night shifts, wore dark sunglasses when outside, slept in dark bedrooms at scheduled times after night shifts and on days off, and received outdoor afternoon light exposure (the ‘light brake’).” “The final dim light melatonin onset (DLMO) of the experimental group was approximately 04:30, close to our target compromise phase position, and significantly later than the control group at approximately 00:30. Experimental subjects performed better than controls, and slept for nearly all of the allotted time in bed. By the last night shift, they performed almost as well during the night as during daytime baseline. ... Relatively inexpensive and feasible interventions can produce adaptation to night shift work while still allowing adequate nighttime sleep on days off.”

Finally, subjects “received four 15-min bright light pulses during each night shift, wore dark sunglasses when outside, slept in dark bedrooms at scheduled times, and received outdoor afternoon light exposure (“light brake”) to keep their rhythms from delaying too far. Control subjects remained in normal room light during night shifts, wore lighter sunglasses, and had unrestricted sleep and outdoor light exposure” (Smith, Fogg, & Eastman, 2009). “The final DLMO of the experimental group was 3:22 $\pm$ 2.0 h, close to the target of 3:00, and later than the control group at 23:24 $\pm$ 3.8 h. Experimental subjects slept for nearly all the permitted time in bed. Some control subjects who slept late on weekends also reached the compromise phase position and obtained more daytime sleep. Subjects who phase delayed (whether in the experimental or control group) close to the target phase performed better during night shifts. A compromise circadian phase position improved performance during night shifts, allowed sufficient sleep during the daytime after night shifts and during the late nighttime on days off, and can be produced by inexpensive and feasible interventions.”

Grundy et al. (2009) conducted a “cross-sectional study of light exposure, sleep duration, physical activity, and melatonin levels ... among 61 female rotating shift nurses (work schedule: two 12 h days, two 12 h nights, five days off).” “Light intensity was significantly higher during sleep for those working at night, while urinary melatonin levels following sleep were significantly higher among those working days. Mean sleep duration for nurses working during the day (8.27 h) was significantly longer than for those working at night (4.78 h. An inverse association between light exposure and urinary melatonin levels was observed; however, this was not significant when stratified by shift group. There was no significant correlation between sleep duration and melatonin, and no consistent relationship between physical activity and melatonin. Analysis of salivary melatonin levels indicated that the

circadian rhythms of night workers were not altered, meaning peak melatonin production occurred at night. This study indicates that two nights of rotating shift work may not change the timing of melatonin production to the day among those working at night. Additionally, in this study, sleep duration was not correlated with urinary melatonin levels, suggesting it may not be a good proxy for melatonin production.”

2. Melatonin

Comperatore and Krueger (1990) recommended coping strategies for eastward and westward travelers and for shiftworkers, including interventions involving melatonin. A later review by Skene, Deacon, and Arendt (1996) suggested that “melatonin is of benefit in facilitating adaptation to forced phase shifts and in conditions of circadian rhythm disturbance.”

Quera-Salva, Defrance, Claustrat, De Lattre, and Guilleminault, (1996) “studied 40 registered nurses, 20 on fixed day-shifts and 20 on fixed night-shifts, to assess whether workers with rapidly shifting schedules were able to adapt their melatonin secretion and sleep-wake cycles.” “Night-shift workers slept significantly more on days off. Napping on the job occurred in 9/20 night-shift workers (mean 114 minutes) between 3 and 6 a.m. ... In night-shift nurses, the acrophase [of sulfatoxymelatonin] was about 7 a.m. on days off, but had a random distribution on workdays. Further analysis revealed two subgroups of night-shift nurses: six subjects (group A).demonstrated a rapid shift in melatonin secretion (acrophase at near 12 noon on work days and at near 7 a.m. on days off) while 14 nurses (group B) did not shift. Group A nurses slept more in the daytime on work days and their total sleep time was the same as day-shift nurses.”

Quera-Salva et al. (1997) also studied the performance and adaptability of the nurses. “Estimated total sleep time during the 15-day experimental period was not significantly different in the dayshift and nightshift nurses. Night nurses shifted regularly to daytime activities on days off and, as a group, were significantly sleep deprived on work days with ... a significant performance decrement during the work period. ... Comparison of performance scores revealed that all nurses performed similarly on days off. Daytime nurses and fast-shifting night nurses had similar scores on work days, while non-shifting night nurses had significantly lower scores at work. Despite similar gender, age, social conditions, and light exposure levels, a minority of the nurses studied possessed the physiological ability to adapt to a fast-shifting sleep-wake schedule of more than 8 hours and were able to perform appropriately in both conditions. This shift was associated with a change in the acrophase of 6-sulfatoxy-melatonin.”

Weibel, Spiegel, Gronfier, Follenius, and Brandenberger (1997) investigated “whether the melatonin (MT) rhythm is adapted to a permanent nocturnal schedule.” The results showed “the great variability in the timing of MT secretion among night workers, in contrast to the homogeneity of their [rectal temperature] rhythm. The exact mechanisms by which night workers adapt their circadian systems have not yet been identified.”

Arendt, Skene, Middleton, Lockley, and Deacon (1997) reviewed the chronobiotic properties of melatonin in humans. “It is able to phase shift strongly endogenous rhythms, such as core temperature and its own endogenous rhythm, together with the sleep-wake cycle. ... There is evidence for synchronization of the sleep-wake cycle, but the available data suggest that it is less effective with regard to endogenous melatonin and core temperature rhythms. When suitably timed, most studies

indicate that fast release preparations are able to hasten adaptation to phase shift in both field and simulation studies of jet lag and shift work. ... However, not all studies have been successful. ... The present data suggest, however, that although sleep-wake can be stabilized to 24 h, entrainment of other rhythms is exceptionally rare.” Sanders et al. (1998) provided another review of the physiology and potential uses of melatonin.

Weibel, Follénus, and Brandenberger (1999) made repeated hormonal measurements every 10 min over a 24 hour period in night-shift workers. The study demonstrated that “there is some, but partial, adaptation of the biological rhythms in these persons. The shift in the melatonin pattern is quite variable from one individual to another. Night work causes a distortion in the cortisol and TSH rhythms. This partial adaptation is also seen in the GH and PRL curves, mainly related to sleep, but whose endogenous component previously described in other experimental situations is found in night workers with a distribution incompletely adapted to the secretory episodes.”

Sharkey, Fogg, and Eastman (2001) conducted a study “designed to isolate melatonin's sleep-promoting effects, and to determine whether melatonin could improve daytime sleep and thus improve night time alertness and performance during the night shift. “Subjects took 1.8 mg sustained-release melatonin 0.5 h before the two daytime sleep episodes during one session, and placebo before the daytime sleep episodes during the other session. ... Melatonin prevented the decrease in sleep time during daytime sleep relative to baseline, but only on the first day of melatonin administration. Melatonin increased sleep time more in subjects who demonstrated difficulty in sleeping during the day. Melatonin had no effect on alertness or the MSLT, or performance and mood during the night shift. There were no hangover effects from melatonin administration.” Sharkey and Eastman (2002) “tested whether melatonin can facilitate phase shifts in a simulated night-work protocol.” “Subjects (n = 32) slept in the afternoons/evenings before night work (a 7-hour advance of the sleep schedule). They took melatonin (0.5 mg or 3.0 mg) or placebo before the first four of eight afternoon/evening sleep episodes at a time when melatonin has been shown to phase advance the circadian clock. Melatonin produced larger phase advances than placebo in the circadian rhythms of melatonin and temperature.”

Horowitz and Tanagawa (2002) reviewed “a number of laboratory studies designed to treat circadian maladaptation to night work by shifting the circadian clock with light, exercise, or melatonin.” “The evidence for the efficacy of non-photoc synchronizers such as exercise and exogenous melatonin is equivocal.” Burgess et al. (2002) discussed “the efficacy of appropriately timed bright light exposure (natural and artificial) and exogenous melatonin administration for producing circadian adaptation to night work.”

Crowley (2003) used “Various combinations of interventions ... to phase-delay circadian rhythms to correct their misalignment with night work and day sleep.” Among other interventions, “Participants took placebo or melatonin (1.8 mg sustained release) before daytime sleep ... but melatonin did not increase the phase delay.” Subsequently, in the same dataset, Smith, Lee, Crowley, Fogg, and Eastman (2005) controlled the various magnitudes of phase delay produced by the other study interventions to determine whether melatonin had a soporific effect. “Although melatonin was associated with small improvements in sleep quality and quantity, the differences were not statistically significant by analysis of variance. However, binomial analysis indicated that melatonin participants were more likely to sleep better than their placebo counterparts on some days with some measures. It

was concluded that, the soporific effect of melatonin is small when administered prior to 7 h daytime sleep periods following night shift work.”

Hansen, Garde, and Hansen (2006) examined “the influence of evening and night shift work, compared to day shift work, on melatonin secretion in nurses in a field setting.” The results indicated “that shift work affected the concentrations of 6-sulphatoxymelatonin in the short term by lower excretion in urine from nurses working the night compared to day shift on a workday and on a day off as well. No significant differences were observed between a workday and a day off when doing day and evening shifts, irrespective of mixed and fixed schedules. Sleep length was reduced workdays (from 6.1-6.8 h) among all nurses, compared to days off (from 7.8-8.7 h).”

Revell et al. (2006) investigated “whether phase advances induced by morning intermittent bright light and a gradually advancing sleep schedule could be increased with afternoon melatonin.” “There were significantly larger phase advances with 0.5 mg (2.5 h, n = 16) and 3.0 mg melatonin (2.6 h, n = 13), compared with placebo (1.7 h, n = 15), but there was no difference between the two melatonin doses. Subjects did not experience jet lag-type symptoms during the 3-d treatment.”

Lewy (2007) explained why “dim light melatonin onset (DLMO) is expected to have an increasingly important role in the diagnosis of circadian phase disorders and their treatment with appropriately timed bright light exposure and/or low-dose melatonin administration.” Touitou and Bogdan (2007) discussed the fact that “a consensus seems to be reached on the possible use of melatonin or its agonists to shift the phase of the human circadian clock, but optimizing the dose, formulation and especially the time of administration require further studies.” Srinivasan, Pandi-Perumal, Spence, Kayumov, and Cardinali (2007; Pandi-Perumal & Cardinali, 2007) also reviewed the literature in their chapter, “Melatonin and Sleep in Shift-workers” in the book, *Melatonin: From Molecules to Therapy*.

3. Modafinil

“Modafinil (Provigil/Alertec/Modavigil/Modalert, in India) is an analeptic drug manufactured by Cephalon, and is approved by the U.S. Food and Drug Administration (FDA) for the treatment of narcolepsy, shift work sleep disorder, and excessive daytime sleepiness associated with obstructive sleep apnea. Modafinil, like other stimulants, increases the release of monoamines, specifically the catecholamines norepinephrine and dopamine, from the synaptic terminals. However, modafinil also elevates hypothalamic histamine levels, leading some researchers to consider Modafinil a ‘wakefulness promoting agent’ rather than a classic amphetamine-like stimulant (as evidenced by the difference in c-Fos distribution caused by modafinil as compared to amphetamine). Despite modafinil’s histaminergic action, it still partially shares the actions of amphetamine-class stimulants due to its effects on norepinephrine and dopamine.” (Wikipedia, validated)

Walsh, Randazzo, Stone, and Schweitzer (2004) assessed “the effect of 200 mg of modafinil compared to placebo on alertness, neurobehavioral performance, and executive function during 4 consecutive simulated night shifts.” “The physiologic sleepiness and neurobehavioral deficits that occurred during the hours of a typical night shift were clearly attenuated by modafinil. Modafinil also had beneficial effects on some measures of executive function.”

Hart et al. (2005) examined “the effects of the alerting agent modafinil on cognitive/psychomotor performance, mood, and measures of sleep during simulated shift work.” They

observed that “abrupt shift changes produced cognitive performance impairments and mood disruptions during night shift work. Therapeutic doses of modafinil attenuated night-shift-associated disruptions, but the larger dose [400 mg] produced some sleep impairments when administered during day-shift work.”

Keating and Raffin (2005) provided a review of the use of modafinil in obstructive sleep apnea/hypopnea syndrome (OSA/HS) and shift work sleep disorder (SWSD). “In SWSD, the drug improves night-time wakefulness without disrupting daytime sleep. Modafinil is generally well tolerated in patients with ... SWSD and has a low abuse potential. Thus, modafinil is a valuable new treatment option for use in patients with excessive sleepiness associated with ... SWSD.”

Czeisler et al. (2005) evaluated the use of modafinil for treating sleepiness in patients with shift work sleep disorder. “Treatment with 200 mg of modafinil reduced the extreme sleepiness that we observed in patients with shift-work sleep disorder and resulted in a small but significant improvement in performance as compared with placebo. However, the residual sleepiness that was observed in the treated patients underscores the need for the development of interventions that are even more effective.”

Wesensten, Killgore, and Balkin (2005) compared caffeine 600 mg, d-amphetamine 20 mg, and modafinil 400 mg “during 85 h of total sleep deprivation to determine the extent to which the three agents restored performance on simple psychomotor tasks, objective alertness and tasks of executive functions.” “At the doses tested, caffeine, dextroamphetamine, and modafinil are equally effective for approximately 2-4 h in restoring simple psychomotor performance and objective alertness. The duration of these benefits vary in accordance with the different elimination rates of the drugs. Whether caffeine, dextroamphetamine, and modafinil differentially restore executive functions during sleep deprivation remains unclear.”

Gill et al. (2006) examined the question of “whether modafinil improved cognitive performance of emergency physicians following overnight shifts” and recorded “symptoms and subjective evaluations of the effect of modafinil on the participants.” “Modafinil increased certain aspects of cognitive function and subjectively improved participants’ ability to attend post-night-shift didactic sessions but made it more difficult for participants to fall asleep when opportunities for sleep arose.”

Schwartz and Roth (2006) reviewed the nature of shift work sleep disorder (SWSD) and research concerning potential countermeasures or interventions in shift workers. “[M]odafinil and armodafinil significantly improve the ability to sustain wakefulness during waking activities (e.g. working, driving), overall clinical condition, and sustained attention or memory in patients with SWSD.”

Batéjat et al. (2006) “assessed the treatment efficacy of a hypnotic-psychostimulant combination to maintain sleep quality, performance, and alertness during a 42-hour simulated military operation.” A 6-hour prophylactic sleep period with zolpidem (ZOL) was followed by an 18-hour continuous work period with administration at midway of 300 mg of slow release caffeine (CAF) or 200 mg of modafinil (MOD). “CAF and MOD maintained performance and alertness throughout the 18-hour work period. As shown by EEG recordings, ZOL improved prophylactic sleep without any deleterious effect on performance immediately after waking. As a result of its positive effects on prophylactic sleep, a lower pressure for slow wave sleep during recovery sleep was observed; nevertheless, zolpidem did not enhance the effects of either psychostimulant on performance. MOD and CAF may be of value in promoting performance and wakefulness during shiftwork or military operations while zolpidem improves prophylactic sleep quality without any deleterious effect after

waking. We concluded that a zolpidem/cafeine or modafinil combination could be useful in a context of environmental conditions not conducive to sleep.”

Nishino and Okuro (2008) provided a review of armodafinil, the (R)-enantiomer of the wake-promoting compound modafinil (racemic), which has a considerably longer half-life of 10-15 hours and is approved for the treatment of excessive sleepiness associated with shift work sleep disorder.

4. Napping

Åkerstedt and Torsvall (1985) collected questionnaires on napping behavior from 282 three-shift workers on rotating schedules. “Fifty-one percent were habitual nappers, but these workers rarely napped when working the afternoon shift or on days off. Four patterns were seen: non-napping (49%), morning shift napping (18%), night shift napping (18%), and both night- and morning shift napping (15%). The napping behavior was closely related to the length of the major sleep episode, which depended on the shift worked and on diurnal type; for example, morning shift nappers rated lower on a morningness/eveningness scale and night shift nappers higher. A study repeated 1.5 years later revealed that non-napping was a very stable behavior, whereas napping in many cases had disappeared, particularly among those who had been transferred to day work. The results indicate that for most shift workers napping compensates for sleep loss caused by the temporal displacement of sleep and modified by diurnal type.”

Chan, Phoon, Gan, and Ngui (1989) studied 593 women electronics “to determine if there was any association between their subjective sleep quality and their sleep patterns.” “The proportion of nappers was higher in night workers than in day, morning, and afternoon shift workers. Nappers had shorter main sleep, but their total sleep duration was generally the same as that of nonnappers. Compared to nonnappers, a higher proportion of day and morning shift workers who napped did not sleep well. Permanent night workers, with the highest proportion of nappers, had more workers sleeping well than rotating night workers. Subjects who slept well were those with longer total and main sleep and generally started the main sleep earlier.”

Lancel and Kerkhof (1991) examined “circadian and homeostatic regulation of sleep in humans.” “In 8 morning types (M-types) and in 8 evening types (E-types), sleep was recorded during 3 successive nights and, after shifting sleep to the daytime, during 3 consecutive days. Night sleep was highly similar in the M-types and E-types. Day sleep clearly differed from night sleep in both types: Day sleep was shorter and had a longer first REMS episode. Furthermore, EEG power density recorded during non-REMS in the delta and theta frequency bands was higher during all day-sleep periods. Remarkably, the enhancements did not occur in non-REMS episode 1 but were delayed. This was interpreted as an inhibition of EEG power density at the beginning of sleep, possibly caused by the time course of body temperature and/or by the higher REMS propensity. Also, clear differences between the types became apparent: Only in the E-types, the non-REMS episodes shortened in response to the shift in bedtime, and probably related to this, the time course of EEG power density over consecutive non-REMS episodes became almost flat. It was concluded that the circadian system exerts not only an influence on sleep duration and REMS propensity, but also affects the time course of the non-REMS process.”

Radosević-Vidacek et al. (1991) examined various sleep characteristics among rotating shift workers (n = 603) and control workers (n = 113). “The results showed the shift workers to have poorer sleep quality than the control group. In addition their main sleep episode was shorter on morning shift

and longer on days off in comparison to controls. Shift workers' main sleep length and frequency of napping were affected by the situation in which they were taken (morning, afternoon, night shift or days off). In the group of shift workers the short main sleep episode on morning and night shifts was compensated by longer sleep on afternoon shift and days off. The short night shift sleep was additionally compensated by napping. However, naps taken on the morning shift did not prove to be compensatory. The length of the main sleep episode was affected by the situation in which sleep was taken also in the control group of workers. In this group only the longer main sleep episode on days off appeared to have a compensatory function for the short main sleep on working days."

Motohashi and Takano (1993) studied the effects of 24-hour shift work on the circadian rhythm in 42 ambulance personnel. "The incidence of circadian periodicity different from 24 h in oral temperature and right and left grip strength was 28.6%, 35.7%, and 47.6%, respectively. The incidence was relatively lower than that of shift workers engaged in a discontinuous 8-hour shift system we reported on previously [(Motohashi, 1992)]. Working conditions allowing ambulance personnel to nap when not called for emergency (for > 4 h) might contribute to a stabilization of circadian rhythms. Furthermore, long nighttime ambulance service amounting to > 100 min was significantly associated with a high incidence of at least one prominent circadian period among oral temperature and right and left grip strength rhythms different from 24 h. In conclusion, 24-hour shift work altered the characteristics of circadian rhythms of ambulance personnel; nighttime naps seemed to have a favorable effect on averting changes in circadian rhythms."

Rosa (1993) conducted "a quasi-experimental study at two worksites with workers on 8- and 12-hour rotating shifts. "Results indicated that most napping occurred prior to the first night shift of the week. Napping prior to the first shift supplemented an apparently adequate quantity of main sleep, whereas napping during the workweek compensated for a reduced quantity of main sleep. Sleep quality was rated higher on no-nap days than on nap days and higher prior to the first shift than during the workweek. These results generally support a compensatory view of napping. Worksite performance/alertness testing, however, indicated diminished alertness during the shift on nap days compared to no-nap days, which was not consistent with a compensatory view of napping. Decreased alertness on nap days may have been associated with poorer sleep quality or with differences in circadian rhythm adaptation on those days."

Matsumoto and Harada (1994) investigated "the effect of naps during duty on recovery from fatigue." Studies were performed on 12 male computer operators in each of two chemical plants working a four-team three-shift system. In one of the plants, the shift workers were able to take a 2 h nap during the night shift (nap group). In the other plant, no nap was taken (no-nap group). Before and after the two consecutive night shifts, both the nap and no-nap groups greatly extended their night sleeps, but the daytime sleep taken by the no-nap group during this period was significantly longer than that of the nap group on both the first and second days. No significant difference was found when comparing the length of the day sleep of the no-nap group with the total sleeping time (night-time nap plus subsequent day sleep) of the nap group. Therefore a night-time nap enables part of the essential sleep to be taken in advance of the day sleep following night work. During night work, both the nap and no-nap groups exhibited an increase in the sleepiness scores and also in the subjective feelings of fatigue concerning the complaints related to drowsiness, dullness and difficulty in concentration. However, it was found that for the no-nap group these effects continued for a large

part of the recovery period following night work. It can therefore be surmised that naps taken during night-time work can be to a certain extent aid recovery from the fatigue caused by that work.”

Sallinen, Härmä, Akerstedt, Rosa, and Lillqvist (1998) examined “The use of a short (< 1 h) nap in improving alertness during the early morning hours in the first night shift” under laboratory conditions. “The results showed that the naps improved the ability to respond to visual signals during the second half of the night shift. Physiological sleepiness was alleviated by the early naps, as measured 50 min after awakening, but not at the end of the shift. Subjective sleepiness was somewhat decreased by the naps. The naps produced sleep inertia which lasted for about 10-15 min. Daytime sleep was somewhat impaired by the 50 min naps. The study shows that a nap shorter than 1 h is able to improve alertness to a certain extent during the first night shift.”

De Martino (2002) compared “sleep patterns in nurses working day and night shifts in a hospital in Campinas (SP), Brazil.” “Day shift workers went to bed at 23h36min, and night workers at 23h52min. The nurses working a day schedule woke up earlier (7h3min) than those working a night schedule when they slept at night. Mean sleep latency was 23min26s for day shift nurses versus 22min50s for night shift nurses; the duration of nocturnal sleep was 7h11min and 9h6min, respectively. Only day workers took naps (mean 2h3min). The average diurnal sleep of night shift nurses was fractionated (two periods, mean time asleep 4h7min and 2h38min). The quality of the nocturnal sleep of night shift workers was better than that of day shift workers. ... Night shift nurses should be able to take naps to compensate for the sleep deficit accrued when they work at night.”

Purnell, Feyer, and Herbison (2002) assessed “the effects on performance, alertness and subsequent sleep of strategic napping on 12-hour overnight shifts.” Twenty-four “male aircraft maintenance engineers working in a forward rotating 12-hour shift pattern volunteered to take part in the study for two work weeks. During the experimental week, each subject was given the opportunity to take a 20-min nap at work between 01:00 and 03:00 h on each of their two overnight shifts. On the control week no naps were taken on the night shifts. ... The results revealed that taking a single 20-min nap during the first night shift significantly improved speed of response on a vigilance task measured at the end of the shift compared with the control condition. On the second night shift there was no effect of the nap on performance. Taking a short nap during either night shift had no significant effect on subjective ratings of fatigue, the level of sleepiness reported while driving to and from work, or subsequent sleep duration and sleep quality.”

Takahashi (2003) provided a review concerning napping. “Napping, when its timing and duration are designed properly, has the potential to improve our daily lives. Laboratory findings indicate that scheduled napping promotes waking function after normal sleep at night, and also counteracts decreased alertness and performance under conditions of sleep deprivation. Since these effects are evident even with naps shorter than 30 min, shiftwork problems may be alleviated by the short nap at the workplace. ... Sleep inertia occurs immediately after napping, but its severity can be minimized by avoiding long naps that may result in awakening from deep non-rapid eye movement sleep. Activities during the post-nap period should also be undertaken carefully.”

Takeyama et al. (2004) examined “the effects of the length and timing of nighttime naps on performance and physiological functions” in an experimental study under simulated night shift schedules. “The experiments had 5 conditions in which the length and timing of naps were manipulated: 0:00-1:00 (E60), 0:00-2:00 (E120), 4:00-5:00 (L60), 4:00-6:00 (L120), and no nap (No-nap). ... Sleep latency was shorter and sleep efficiency was higher in the nap in L60 and L120 than that

in E60 and E120. Slow wave sleep in the naps in E120 and L120 was longer than that in E60 and L60. The mean reaction time in L60 became longer after the nap, and faster in E60 and E120. Earlier naps serve to counteract the decrement in performance and physiological functions during night shifts. Performance was somewhat improved by taking a 2-hour nap later in the shift, but deteriorated after a one-hour nap. Naps in the latter half of the night shift were superior to earlier naps in terms of sleep quality. However performance declined after a 1-hour nap taken later in the night shift due to sleep inertia. This study suggests that appropriate timing of a short nap must be carefully considered, such as a 60-min nap during the night shift."

This same group provided a review of nighttime napping (Takeyama, Kubo, & Itani, 2005). "Nighttime napping is an effective measure to prevent adverse effects due to night shift work. A characteristic of nighttime nap is that it can result in considerably deeper sleep. Several studies have shown that taking nighttime naps suppressed increasing sleepiness, decreasing alertness during the period following awaking from a nap, and prevented disturbance of circadian rhythm ('anchor sleep'). The length of daytime sleep after night shift, when combined with a nighttime nap, is shorter than that without nap. ... Recently, participatory method for improvement of working condition has expanded worldwide. A characteristic of the activity is using action checklist and group work, and heightening motivation to improvement working condition between worker and manager."

Hirose (2005) reviewed his "research findings on sleep and health for shift workers at a bakery and a dish factory." "Our medical examinations revealed that rises in blood pressure (BP) were frequently observed in male bakery workers on the fixed night shift. They took a two-hour nap from 1:00 to 3:00 during the night shifts according to our advice. As a result, their diastolic BP significantly decreased in subsequent years."

Ribeiro-Silva et al. (2006) assessed "whether the time devoted to daily activities (sleep, rest, leisure, housework, commuting, personal needs, care of children or other people, non-paid work, and study) is related to the number of worked hours and to nap-taking during the night shift." "The field study took place [with nurses] at two public hospitals in Rio de Janeiro, Brazil. ... All workers who had at least one working night were analyzed as to nap-taking on the job. They were classified according to the sleep occurrence during the night shift-the sleep group and the non-sleep group, both of which were compared to daytime workers. ... Time devoted to sleep and leisure varied according to the number of working hours, being significantly reduced in those submitted to longer work hours. Results close to significance point to a reduction in the time dedicated to housework among workers with long work hours. The time spent on sleep/rest per working night did not differ according to the number of worked hours. A tendency was observed for those who have two jobs to devote more time to sleep/rest on the job. The time of personal needs was significantly lower among those who did not sleep on the job as compared to day workers. The total sleep time was significantly lower among those who did not sleep on the job, as compared to day workers and to those who slept on the job. As to home sleep length, workers who slept and those who did not sleep on the job were similar and slept significantly less than exclusively daytime workers. Sleeping on the job during the night shift seems to partially compensate for the shorter sleep at home among night workers and may play a beneficial effect in coping with two jobs."

Schweitzer, Randazzo, Stone, Erman, and Walsh (2006) evaluated "the effects of napping, caffeine, and napping plus caffeine on performance and alertness in both laboratory and field settings." In the laboratory study there was "an evening nap opportunity before the first 2 of 4

consecutive simulated night shifts plus placebo taken all 4 nights, caffeine taken nightly, the combination of the nap and caffeine conditions, or placebo.” “Napping, caffeine, and their combination all improved alertness and performance as measured by Maintenance of Wakefulness Test and Psychomotor Vigilance Task, but the combination of napping and caffeine was best in improving alertness.” In the field study there was “an evening nap on the first 2 of 4 consecutive night shifts plus caffeine taken nightly versus placebo taken nightly without naps.” “Napping plus caffeine improved performance as measured by Psychomotor Vigilance Test and decreased subjective sleepiness in individuals working the night shift.” “Napping plus caffeine helps improve performance and alertness of night-shift workers.”

Philippens, Vanwersch, Jongsma, Groen, and Bouwman (2006) validated the marmoset monkey model as a model for testing the effects of drugs on performance during time shift work as is the case in many military operations. “It was proven that the homeostasis in marmoset monkeys after sleep deprivation is similar to the human homeostasis: The sleep intensity after a night of sleep deprivation, which will happen during late night or early morning duty, is increased in the first hours of sleep similar to human. Furthermore, a short nap by these animals before the sleep deprivation period can prevent most detrimental effects on performance and activity, as is the case in humans.”

5. Sleep Aids

Riedel, Quasten, Hausen, and O’Hanlon (1988) noted that “The average duration of day-sleep in rotating shift workers is 5 to 6 hours. Midazolam, triazolam and temazepam all possess short elimination half-lives, i.e., 2, 4 and 8 hours, respectively. This suggests that these drugs should be largely free from residual effects and therefore not impair performance in real-life tasks.” They concluded “that midazolam 15 mg can be recommended for use by rotating shift workers in order to cope with transient insomnia caused by poor adaptation to night-shift, and that in general no residual effects will be present 6.5 hours after ingestion. Temazepam 20 mg is less likely to improve day-sleep, but is absolutely free from residual sedative effects. Triazolam 0.5 mg can not be recommended because it is less likely to improve day-sleep and is unsafe to drive with 6.5 to 8.5 hrs after ingestion.”

Stone and Turner (1997a) provided a review of sleep promotion techniques. “Optimization of the sleeping environment and avoidance of substances such as caffeine and alcohol before sleep are the best initial approach. Timing sleep to coincide with some of the normal sleep period where possible will improve sleep quality in shiftworkers. ... Hypnotic drugs may be of benefit to alleviate sleep disturbance experienced by shiftworkers Selection of the most appropriate medication must take into account required duration of action and possible residual effects of the drug on alertness. Hypnotics may be useful, particularly in middle-aged individuals who already have disturbed sleep, on those occasions when poor sleep is anticipated, for example ... after the initial change to night duty. Over-the-counter preparations should be avoided whenever possible unless it is known that they are not associated with residual sequelae.”

Porcù, Bellatreccia, Ferrara, and Casagrande (1997) “evaluated the effects of 20 mg of temazepam on daytime sleep, the subsequent levels of nocturnal alertness/sleepiness, and performance in a laboratory simulation of acute night shift.” “Temazepam resulted in being an effective diurnal hypnotic, increasing total sleep time with no residual detrimental effects on sleepiness and performance and with an increase in the ability to stay awake.” Casagrande, Ferrara, Curcio, and Porcù (1999) examined the usefulness of pencil and paper tests of vigilance to assess

attentional performance degradation due to sleep loss and/or inversion of the sleep-wake cycle. They “evaluated the sensitivity of a three-Letter Cancellation Task (3-LCT) in revealing nighttime variations of vigilance in a laboratory simulation of acute night shift, after a diurnal sleep with placebo (PLC) or temazepam (TMZ). ... We also found some effects of TMZ, which in the first nocturnal session caused a slowing down of visuo-attentive performance.”

Richardson and Tate (2000) clarified the differing etiologies and natures of jet lag and shift lag. They noted that “Practical issues sharply limit the application of artificial lighting to all shiftwork settings, however, and the role for a pharmacological chronobiotic agent capable of accomplishing the same end is potentially very large” (Copinschi et al., 1995; Jamieson et al., 1998). They cite the example of zolpidem.

Garbarino et al. (2002a) “investigated sleep habits, prevalence of sleep disorders, sleepiness on the job, and hypnotic drug intake (Benzodiazepines, Zaleplon, Zolpidem, or Zopiclone) in a population of Italian state police officers.” “In shiftworkers, there was a higher prevalence of difficulty in initiating sleep; in addition, these individuals had a sleep latency that exceeded 20 min, and they experienced early awakenings. No significant differences in daytime sleepiness and drug intake existed between the 2 groups. Self-evaluation of the number of hours that individuals slept each night and during a 24-hr period revealed that shiftworkers required more sleep. The results indicated that shiftworkers experienced a lower quality of sleep than non-shiftworkers, but the former did not report increased daytime sleepiness or increased hypnotic drug intake (i.e., Benzodiazepines, Zaleplon, Zolpidem, or Zopiclone). Shiftworkers seemed to compensate for the poor quality of their sleep by sleeping for a greater number of hours during 24-hr periods than the non-shiftworkers.”

Hart, Haney, Nasser, and Foltin (2005) conducted a 21-day simulated shift work study in which “the acute effects of the stimulant, methamphetamine were examined, and the effects of the hypnotic, zolpidem, and the combination were assessed during the shift after drug administration.” Volunteers “received a single oral methamphetamine dose (0 or 10 mg) 1 h after waking, i.e., before task performance, and a single oral zolpidem dose (0 or 10 mg) 1 h before bedtime under 2 shift conditions: day shift and night shift. When participants received placebo at both dosing times, performance on some psychomotor tasks (e.g., the digit-symbol substitution task) and on some measures of mood (e.g., ratings of “Energetic”) were disrupted during the night shift, relative to the day shift. Methamphetamine alone eliminated virtually all shift-related disruptions, while zolpidem alone and the drug combination produced few effects. These data indicate that shift changes produce performance impairments and mood alterations that are improved by a single low to moderate dose of methamphetamine. Zolpidem, given alone or in combination with methamphetamine, did not alleviate most shift-change mood and performance effects.”

Batéjat et al. (2006) “assessed the treatment efficacy of a hypnotic-psychostimulant combination to maintain sleep quality, performance, and alertness during a 42-hour simulated military operation.” A 6-hour prophylactic sleep period with zolpidem (ZOL) was followed by a 18-hour continuous work period with administration at midway of 300 mg of slow release caffeine (CAF) or 200 mg of modafinil (MOD). “CAF and MOD maintained performance and alertness throughout the 18-hour work period. As shown by EEG recordings, ZOL improved prophylactic sleep without any deleterious effect on performance immediately after waking. As a result of its positive effects on prophylactic sleep, a lower pressure for slow wave sleep during recovery sleep was observed; nevertheless, zolpidem did not enhance the effects of either psychostimulant on performance.”

6. Shift Systems, Plans, and Schedules

A shift system specifies the ratio of work days (W) to free days (F) in a shiftwork schedule, and is useful for the classification and analysis of schedules. A free day is defined as a day on which a shift does not start. A shift plan (*rota*) determines the sequence of W and F within the system. The notation used for a plan may include “D,” “S,” and “N” for the W periods, day, swing and night, respectively, and “O” (off) for F periods. A shift schedule takes into account the plan and (Miller, 2006):

- The number of crews, the optimal number being four
- The employment ratio, to take into account holidays, annual leave, sick leave, training time, etc.
- Shift type, i.e., fixed versus rotating shifts, forward (clockwise) versus backward (counterclockwise) directions of rotation, slow versus fast rotation
- Shift length, especially 8-hour versus 12-hour shifts
- Shift overlap
- Shift differentials, in terms of different hourly pay rates or different shift lengths across day, swing and night shifts
- Alignment of workdays and days off with weekends
- Shift change times, especially when to begin the morning shift to allow as many shiftworkers as possible to sleep well at night

Knauth, Rohmert, and Rutenfranz (1979b) took into account the numerous theoretically possible shift systems and chose sensible shift systems with the aid of objective work-physiological criteria, e.g., the duration of the daily working time, the positioning and duration of sleep and recreation time. “With an agreed 40 h week shift, systems with a weekly working time of 42 h are more advantageous. If the shifts are equally attended over 24 h the following shift systems are recommended: when you have 8 h shifts the relation between the number of working days and the number of free days should be ‘3 n/n’, whereby n must be larger than 1, within one shift *rota*. In the exceptional case of a 12 h shift the corresponding relation should be ‘2 n/n’. Further unsuitable and recommended shift plan examples are demonstrated for these shift systems.” This is the paper that defined shift systems and triggered the eventual publication of Miller’s manual (Miller, 2006).

Naitoh (1980) discussed “A new interdisciplinary science of chronopsychology” with respect to its “methods, concepts, theories, and applications, especially to shiftwork and transmeridian dyschronism (‘jet lag’).” “The source materials on circadian components of human effectiveness in shiftwork ... suggest that the timing of the work period should be optimized on the basis of the fundamental circadian rhythms to assure the best time for work and rest. Differences between the adjustment of shiftworkers and jet travelers to new work environments are discussed, with suggestions on how to accelerate this process.”

Czeisler et al. (1982) noted that “Workers on rotating shifts dislike those aspects of their work schedules that violate circadian sleep-wake cycle physiology. Work schedule satisfaction, subjective health estimates, personnel turnover, and worker productivity improve when schedules are introduced that are designed to incorporate circadian principles.”

Knauth, Eichhorn, Löwenthal, Gärtner, and Rutenfranz (1983) suggested that “The reduction of nightwork is an important preventive measure to limit possible negative effects of night shifts on well-

being, health and social life.” “An example of a gradual reduction of nightwork in a group of transport workers at an airport is presented. After having carefully analyzed the real number of persons needed during nighttime for loading and unloading aircrafts the number of shiftworkers who had to work between 02.00 and 06.00 h was reduced in a first step from 104 to 66 and in a second step to 38 persons.”

Fukey (1985) saw that “If Air Force supervisors and workers were more aware of their daily body rhythms and what effect rotating shift work has on those rhythms, they could better plan their shift work schedules, as well as sleeping and eating times.” “This report illustrates some of the basic biological rhythms of the body and how knowledge of those rhythms can be used to determine a ‘best’ rotating shift work schedule, ‘best’ shift tour length, ‘best’ shift work sleeping time and ‘best’ shift work eating time.”

Comperatore and Krueger (1990) noted that “Jet lag and shift lag have similar physiological consequences, but shift lag is a more complex problem. The most severe desynchronization may be experienced by airline personnel making transmeridian flights. Coping strategies for eastward and westward travelers and for shiftworkers are recommended, as are interventions involving melatonin.” Subsequently, Comperatore et al. (1992) reported that, for U.S. Army Aviation operations, “Strategies in the scheduling of sleep, meals, work, and exercise are currently under study with the purpose of identifying patterns that assist in the physiological adaptation to nighttime duty hours. These coping strategies are composed of countermeasures designed to prevent the sleep loss and chronic fatigue usually associated with rapid transitions from daytime to nighttime duty hours.”

Knauth (1995b, 1993, 1996, 1997) reported “The results of some intervention studies on the effects of the change from weekly rotating to quicker rotating shift systems.” His observations led to the following recommendations: “(1) Nightwork should be reduced as much as possible. If this is not possible, quickly rotating shift systems are preferable to slowly rotating ones. Permanent nightwork does not seem to be recommendable for the majority of shiftworkers. (2) Extended workdays (9-12 hours) should only be contemplated when the nature of work and the workload are suitable for extended working hours, and the shift system is designed to minimize the accumulation of fatigue and toxic exposure is limited. (3) An early start for the morning shift should be avoided. Flexible working time arrangements can be achieved in all shift systems. The highest flexibility is possible in the so-called ‘time autonomous groups’. (4) Quick changeovers (e.g., from night shift to afternoon shift on the same day) should be avoided. The number of consecutive working days should be limited to five-seven. Every shift system should include some free weekends with at least two consecutive days off. (5) The forward rotation (phase delay, clockwise rotation: morning/evening/night shift) would seem to be most preferred.” No research to date contradicts these recommendations.

Glaser (1996) conducted a literature review that assessed “the effects of Quality of Life (QOL) and related factors that affect turnover and performance in the private sector.” “Support was found for the spillover model (attitudes from one sector of life, such as work, carry over into another sphere, such as home). However, determining the causal direction of the work-nonwork relationship is still speculative. Some evidence has been found for the effects of family responsibilities on work (e.g., tardiness). Possible variables that influence turnover include pay/salary, health, and shiftwork. The QOL/performance relationship is suggestive at best given the lack of research.”

Gärtner and Wahl (1998) noted that “Shift scheduling is based on some representation of shift schedules.” “The number of different representations currently used is high, and one might expect

small practical differences between these representations. However, an analysis of several prominent representations revealed strong differences regarding possible outcomes of the scheduling process and the effort needed for their assessment. Limitations of some representations do not only concern specific *rota* design issues, such as different staffing levels or different workhours, but also rather simple and straightforward *rotas*. Furthermore, there is no single representation that is strictly and unequivocally better than the others. Most representations simplify the development of some *rotas*, while they make it very difficult or even impossible to develop others. Therefore, both designers and the computer systems used for design should use and support several representations and therefore allow smooth transitions between them. In addition knowledge about *rota* construction techniques should be maintained, as it may ease assessment dramatically.” The methods in Miller’s manual may help to deal with this problem (Miller, 2006).

Gissel and Knauth (1998) “developed a knowledge-based software system to support the participatory design and implementation of shift systems as a joint planning process including shift workers, the workers’ committee, and management.” “During the first 2 phases of [using] the system, important basic information about the tasks to be carried out is provided for the user. During the 3rd phase this approach uses the problem-solving method of case-based reasoning to determine a shift *rota* which has already proved successful in other applications. It can then be modified in the 4th phase according to the shift workers’ preferences. The last 2 phases support the final testing and evaluation of the system. The application of this system has shown that it is possible to obtain shift *rotas* suitable to actual problems and representative of good ergonomic solutions.”

Knauth (2001) added the observation that “Implementation barriers may be caused by deficiencies in the knowledge, skills, motivation, or support of those involved in the process of implementation of a new shift system.” “There is no ‘one and only’ way of planning and implementing a new shift system. However, if the following factors of success are taken into consideration there is a better chance that workers will accept a new shift system: worker participation, information, communication, training, promoter commitment, professional project management, tailor-made solutions and an adequate organizational framework. ... The most important measures to cope with resistance to change of shift systems are: worker participation, information, communication, training, promoter commitment, professional project management, tailor-made solutions and an adequate organizational framework.”

Concomitantly, Manuaba (2001) reported an “effort in carrying out an integrated ergonomics approach known as ‘SHIP’ (systemic, holistic, interdisciplinary and participatory)” in Bali. “[N]ight and shift work that is recently increasingly applied in the tourism industry must also be designed and organized through this approach. In fact, however, economic factors have still been the predominant reason for workers to accept any type of night and shift work decided by the management, without taking into account possible impacts and consequences.” Examples were presented. “Cultural or religious activities still presented constraints for workers as they carried out subsequently the night work.”

Kogi (2004) reviewed “Various support measures useful for promoting joint change approaches to the improvement of both shiftworking arrangements and safety and health management systems.” “A particular focus was placed on enterprise-level risk reduction measures linking working hours and management systems.” “Both the guidelines and the plant maintenance work checkpoints were found

to commonly cover multiple issues including work schedules and various job-related risks. This close link between shiftwork arrangements and risk management was important as shiftworkers in these industries considered teamwork and welfare services to be essential for managing risks associated with night and shift work. Four areas found suitable for participatory improvement by managers and workers were work schedules, ergonomic work tasks, work environment and training.”

Knauth, Jung, Bopp, Gauderer, and Gissel (2006) helped deal with very irregular *rotas* and many short-term schedule deviations experienced by some employees of TV companies, such as those who produce remote TV programs. A “working group of employers, council representatives, and researchers developed a so-called bonus system. Based on the criteria of the BESIAK system, the following list of criteria for the ergonomic assessment of irregular shift systems was developed: proportion of night hours worked between 22:00 and 01:00 h and between 06:00 and 07:00 h, proportion of night hours worked between 01:00 and 06:00 h, number of successive night shifts, number of successive working days, number of shifts longer than 9 h, proportion of phase advances, off hours on weekends, work hours between 17:00 and 23:00 h from Monday to Friday, number of working days with leisure time at remote places, and sudden deviations from the planned shift *rota*. Each individual *rota* was evaluated in retrospect. If pre-defined thresholds of criteria were surpassed, bonus points were added to the worker's account. ... In general, the most promising approach to cope with the problems of shift workers in irregular and flexible shift systems seems to be to increase their influence on the arrangement of working times. If this is not possible, bonus point systems may help to achieve greater transparency and fairness in the distribution of unfavorable working-time arrangements within a team, and even reduce the unnecessary unfavorable aspects of shift systems.”

Knauth and Hornberger (2003) provided a review that focused “on measures that can be taken to optimize the well-being of shift workers and to identify ill-health at an early stage.” They examined “specific aspects of the design of shift systems, taking account of variation in the views and circumstances of employees, and strategies to combat sleepiness at work and elsewhere. Although an ideal shift system does not exist, a holistic approach comprising education of managers, employees and their families can ameliorate some of the health consequences.”

Coleman (1995) showed that there are many custom schedules that may be designed to optimize productivity, safety and health. Explanations of systems, plans and schedules were provided by Miller (2006). A number of plans are also presented in Chapter 4 of Shiftwork, Safety and Performance (Westfall-Lake & McBride, 1997), which is the best reference for the design and use of 5-crew plans (pp. 87-96).

The research and consulting company, Circadian Technologies, Inc. (www.circadian.com), publishes numerous newsletters, reports and white papers that summarize research findings. Free white papers include:

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- Napping on the Job: Policies & Benefits in Extended Hours Operations

- Physical Exercise and Working Extended Hours
- Planning and Budgeting for Improvements in Extended Hours Operations
- Reducing the Costs of Continuous Operating Schedules in Tough Economic Times: 4 Key Considerations & 7 Creative Solutions of Immediate Savings NEW
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- Shiftwork Lifestyle Training: Employee and Employer Benefits
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- Health in Extended Hours Operations - the study identifies the specific health problems commonly related to 24/7 operations and present recommendations and intervention programs that will improve employee health.
- Overtime in Extended Hours Operations: Benefits, Costs and Liabilities - a comprehensive look at the overtime that will allow managers to make informed decisions about how to manage overtime efficiently and safely.
- Shiftwork Practices 2007 - the world's only comprehensive benchmarking survey and best practices assessment for 24/7 operations. Featuring data from 400 facilities & 290,000 shiftworkers.
- The Practical Guide to Managing 24-Hour Operations - Includes over 100 tips on how to best run a shiftwork facility.

G. WORKER HEALTH

Rentos and Shepard (1976) edited the proceedings of a symposium concerning Shiftwork and Health. Åkerstedt, Froberg, Levi, Torsvall, and Zamore (1977) reviewed "the results of an interdisciplinary study on shift work and health." Rutenfranz et al. (1977) discussed "the effects of shift work on health and the physiological problems raised by the phase-shifting of the circadian cycle in night workers." "Summaries of the existing knowledge of the effects of shift work on performance efficiency, accidents, and family and social life are then given, and a set of criteria for designing optimal shift systems is proposed. Next, the questions of selection for shift work and the provision of health services for shiftworkers are discussed." Wojtczak-Jaroszowa (1977) reviewed "the results of physiological and psychological studies related to night and shift work."

Tasto, Colligan, Skjei, and Polly (1978) investigated the psychological and physiological effects of working unconventional hours. Torsvall and Åkerstedt (1978) summarized a 5-year research project called "Shift work and well-being." Dunham (1979) dealt with physical, psychological, and sociological problems often associated with shiftwork.

Angersbach et al. (1980) conducted a “retrospective cohort study ... in a firm in the chemical industry.” “The incidence of sickness in general did not differ between permanent shift workers and day workers, but was highest in shift workers who transferred later to day work mostly for medical reasons. Furthermore, on the average, shift workers were sick for longer periods than day workers. Significantly more shift workers than day workers consulted the occupational health services about gastrointestinal complaints than day workers. Shift workers had more frequent gastrointestinal diseases than day workers and more severe ones such as peptic ulcers. Gastrointestinal diseases were more frequent in the following groups of the shift workers: Young (21 to 25 years) and unmarried subjects, heavy smokers and subjects with a past history of gastrointestinal diseases. No differences between shift workers and day workers could be detected concerning cardiovascular diseases including myocardial infarction. Psychosomatic disorders were seldom diagnosed and did not differ between shift and day workers. Surprisingly, skeletal diseases including the sequelae of accidents and injuries occurred more often in the shift workers' cohort; the possible cause of this was a higher incidence of moonlighting in shift workers or other activities beside work.”

Koller (1983; Koller, Haider, Kundi, & Cervinka, 1985) split 300 matched cases of permanent shift workers, day workers, and drop-outs in an oil refinery into four groups corresponding in age and years at work. “In terms of an overall score ... health was found to deteriorate with age, but to a different degree in the shift and day workers. In shift workers, a steep decrease in score during the first years at work was followed by a continued slight decrease in middle age; from the age of 41 years onwards there was a further pronounced decrease in score. In day workers a stabilization in score was observed up to middle age, with a distinct decrease thereafter. The difference in health parameters between the groups was only small in younger workers (up to 12 years at work), but became striking and significant with increasing age. In the permanent shift workers an increasing health risk was clearly indicated by increases in absence due to sickness, gastro-intestinal and cardiovascular diseases and unspecific health complaints (sleep disturbances, premature fatigue). A specific kind of behaviour during illness (e.g. less readiness to consult a doctor) was also observed in the shift workers. In the permanent day workers health risks were not strictly age-related. Whereas absence due to sickness was highest in young workers, morbidity for respiratory diseases and injuries was significantly elevated in the older workers; the frequency of subjective complaints increased up to middle age and decreased thereafter. In drop-outs with considerable prior exposure to shift work, strikingly high rates of absence due to sickness and excess rates of cardiovascular diseases were observed.”

Moore-Ede and Richardson (1985) noted that “the kinds of repeated shifts over a number of years experienced by shift-workers on rotating schedules induce sleep-wake disorders, gastrointestinal pathology, and an increased risk of cardiovascular disease.” “There is significant inter-individual variation in the ability to adapt and also a deterioration with age. Evidence is accumulating that poor adapters present with a Shift Maladaptation Syndrome with characteristic pathological manifestations.”

Folkard, Minors, and Waterhouse (1985) divided into the problems associated with shiftwork into 3 main interrelated domains, medical, biological and social. “The biological problems are evidenced in disturbed rhythms and sleep, the medical problems in improved objective and, in particular, subjective health, and the social problems in impoverished family and social life. ... Three main types of intervention are discussed that might alleviate the shift workers' problems. These centre on the type of shift system, the scheduling of *Zeitgebers* or synchronizers, and the counseling of individuals.”

Ottmann et al. (1989) assessed the subjective health status of 2,659 shift-working and 1,303 day-working police officers. "Factor analysis revealed that all the symptoms included in the questionnaire could be grouped into six factors. The prevalence rates of complaints showed that four of these factors (autonomous symptoms, musculo-skeletal symptoms, disturbance of appetite and indigestion, respiratory infections) were influenced by the main effects of age and shift work. Across all age classes the age-related changes in prevalence rates were strengthened by shift-work. In the other two factors (nervous symptoms, gastro-intestinal symptoms) an additional interaction effect could be observed. While the prevalence rates of the day-workers increased with age, those of the shift-workers decreased in the oldest age class."

Cole, Loving, and Kripke (1990) noted that "There is little rigorous evidence that shiftwork produces specific psychiatric disturbances." "Substantial evidence suggests that shiftworkers are prone to increased drug and alcohol consumption, but the frequency with which this leads to actual drug abuse disorders has never been adequately defined. A preponderance of studies suggests that symptoms of a 'neurotic' character are over-represented among nightshift workers. The nature of these symptoms needs to be clarified with modern psychiatric nomenclature. It seems likely, based on certain experimental work, that nightshift work may at times exacerbate mood disorders, leading to an impression of 'neurotic' disturbance. At the same time, some conditions of shiftwork might actually palliate mood disorders. Therefore, a reexamination of these issues is needed with improved research designs and more careful characterization of the nature of workers' complaints, their psychiatric histories (i.e., personal and family histories of mood disorders and other psychopathology), and possible specific effects of particular shiftwork rotation schedules. Use of bright light to alleviate mood disturbances associated with shiftwork needs extensive empirical testing."

Colligan and Rosa (1990) reviewed "Advantages and disadvantages of different work schedules—fixed days, fixed afternoons, fixed nights, and rotating shifts— ... in terms of social satisfaction and adjustment for the worker and his or her family. The chapter also calls for new studies assessing the impact of changes in the complexion of the workforce and composition of the American family on shiftworker satisfaction."

Costa, Cesana, Kogi, and Wedderburn (1990) edited the proceedings of the 9th International Symposium on Night and Shift Work, held in Verona, Italy, entitled "Shiftwork: Health, Sleep and Performance." Kennedy (1990) dealt with the issues of "Shiftwork as related to stress claims under workers' compensation statutes." He noted that "Today, if a claimant can show that a medical condition was caused by work, or that a psychiatric or emotional condition resulted from allowed injuries or occupational diseases, workers' compensation requirements usually are met. Stress-related claims, however, are less predictable; they are resolved through state workers' compensation boards and state appeals courts, with almost no federal involvement." Scott and LaDou (1990) reviewed "diseases that are aggravated by shiftwork (gastrointestinal and cardiovascular disorders), the potential of shiftwork to adversely affect pregnancy, shift maladaptation syndrome, and the ability of shiftwork to exacerbate existing disorders and interfere with pharmacological treatments." They offered "guidelines for pre-employment screening and medical surveillance of shiftworkers."

Harrington (1994) examined "The link between shift work and increased cardiovascular morbidity and mortality." "The case for an association with gastrointestinal disease remains quite good. Evidence of poorer work performance and increased accidents, particularly on the night shift, is persuasive, although individual factors may be as important as workplace factors. Correct shift work

scheduling is important and for rotating shifts, rapid forward rotation is the least disruptive option. The compressed working week of 10 to 12-hour shifts is gaining popularity but evidence is too scant at present to suggest there are many long-term health and safety risks provided the rest day block is preserved. Optimal hours for the working week cannot be formulated on present scientific evidence, though working more than 48-56 hours a week probably carries serious health and safety implications. The inherent conflict between the interest of the worker and the enterprise over unsocial hours can be mitigated by improvements in working conditions especially at night and by advice to the worker on coping strategies."

Barton et al. (1994) examined "the change in the direction of shift rotation from a delaying to an advancing system on health and wellbeing." "The change from a delaying to an advancing system resulted in an increase in sleep difficulties between successive afternoon shifts, but a decrease in social disruption. There was little evidence of impaired health on the advancing compared with the delaying system." Barton, Spelten, Totterdell, Smith, and Folkard (1995) also studied "the impact of the number of consecutive night shifts worked on the health and well-being of two groups of nurses (permanent night and rotating shift)." "Results showed clearly the impact of the number of consecutive nights worked on health and well-being, not directly, but indirectly through the impact on sleep duration and sleep quality. Sleep duration was shown to increase with more consecutive nights worked. This in turn was found to predict sleep quality, which in turn was found to be the stronger direct predictor of psychological and physical ill-health i.e. better health was associated with longer and better quality sleeps."

A factor analyses of health complaints in groups with different length of shiftwork exposure by Nachreiner, Lubeck-Ploger, and Grzech-Sukalo (1995) showed that "the structure of these complaints changes with increasing shift experience, indicating the emergence of a shift-specific pattern of health complaints." "After about 15 years of shiftwork, complaints related to disturbances of circadian-controlled functions can be found in the first factor whereas other complaints have their dominant loadings on a separate factor, representing general, non-shift-specific impairments."

Spurgeon, Harrington, and Cooper (1997) discussed the European Community Directive on Working Time. They reviewed "the current evidence relating to the potential effects on health and performance of extensions to the normal working day." They concluded that "there is currently sufficient evidence to raise concerns about the risks to health and safety of long working hours."

Scott, Monk, and Brink (1997) "explored the link between exposure to shiftwork and the prevalence of major depressive disorder (MDD) during and after the shiftwork experience." "In addition to confirming previous findings regarding the detrimental effects of shiftwork on sleep and social/domestic factors, there was an unexpectedly high prevalence of MDD identified, occurring during or after shiftwork, with a higher rate for women than for men. The study also provided suggestive evidence that increasing exposure to shiftwork (up to 20 years) was associated with an increased lifetime risk of MDD."

Scott (2000) noted that "Certain medical conditions may be aggravated by shift-work scheduling, and shift workers are at increased risk of experiencing cardiovascular, gastrointestinal, and reproductive dysfunction." "Vulnerable individuals may develop clinical depression when working shifts. Primary care practitioners may intervene by providing medical surveillance and educational programs for shift-working patients and their families."

Kogi (2001) asked “[H]ow and to what extent we can ensure healthy work life for shiftworkers?” They suggested three directions: “(a) comprehensive action to avoid risk-enhancing conditions based on general guidelines, (b) risk control as to workload, worksite ergonomics and risk reduction, and (c) support for flexible and restful working life.” “[W]e need to combine (a) comprehensive measures to improve work schedules and job life, (b) strict risk management and (c) locally adjusted participatory steps for continual improvement.” Knutsson (2003) reviewed “the evidence for a relationship between specific medical disorders and working at night or on shift systems.” “The strongest evidence exists for an association with peptic ulcer disease, coronary heart disease and compromised pregnancy outcome.”

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Costa et al. (2004) described a project that “brought together researchers from 9 EU-Countries.” Their efforts “resulted in a number of actions, in particular the following: (a) There is an urgent need of defining the concept of flexible working hours, since it has been used in many different and even counterintuitive ways; the most obvious distinction is where the influence over the working hours lies, that is between the ‘company-based flexibility’ and the ‘individual-oriented flexibility’; (b) The review of the Legislation in force in the 15 European countries shows that the regulation of working times is quite extensive and covers (Council Directive 93/104/EC) almost all the various arrangements of working hours (i.e., part-time, overtime, shift, and night work), but fails to provide for flexibility; (c) According to the data of the Third EU Survey on Working Conditions, longer and ‘irregular’ working hours are in general linked to lower levels of health and well-being; moreover, low (individual) flexibility and high variability of working hours (i.e., company-based flexibility) were consistently associated with poor health and well-being, while low variability combined with high autonomy showed positive effects; (d) Six substudies from different countries demonstrated that flexible working hours vary according to country, economic sector, social status, and gender; overtime is the most frequent form of company-based flexibility but has negative effects on stress, sleep, and social and mental health; individual flexibility alleviates the negative effects of the company-based flexibility on subjective health, safety, and social well-being; (e) The literature review was able to list more than 1,000 references, but it was striking that most of these documents were mainly argumentative with very little empirical data.”

Portela, Rotenberg, and Waissmann (2004) “tested the hypothesis that the prevalence of diseases, sleep complaints, and insufficient time for nonprofessional activities (family, leisure, and rest) are higher among night than day workers [258 female nurses].” “Reports of migraine and need of medical care the 2 weeks before the survey were more prevalent among day than night workers. Migraine headaches occurred less frequently among night than day workers... Reports of mild emotional disorders (mild depression, tension, anxiety, or insomnia) were less frequent among night and ex-night workers than day workers who never had worked a night job. ... Among night workers, a significant relation was found between years working nights (more than 10 yrs) and high cholesterol values.”

Costa (2004) noted that “The impact of shift and night work on health shows a high inter- and intra-individual variability, both in terms of kind of troubles and temporal occurrence, related to various intervening factors dealing with individual characteristics, lifestyles, work demands, company

organisation, family relations and social conditions.” “As the goal is the optimisation of shiftworkers’ health, it is necessary to go beyond the health protection and to act for health promotion.”

de Castro Moreno and Louzada (2004) discussed “the possible impacts of work schedules on shift workers’ and night workers’ health.”

Raediker et al. (2006) conducted a “Statistical analyses of the relation between the amount of working hours and impairments to health, based on data from a European survey on working conditions in 2000.” The data revealed that “there is a substantial correlation between the number of working hours per week and the frequencies of health complaints. This applies to both musculo-skeletal disorders as well as to psycho-vegetative complaints. The relationship of the duration of the exposure to working conditions to health impairments is moderated by a great number of individual (e.g., age) and situational (e.g., shift-work) variables, showing additive or interactive effects for which selected examples have been presented. In general, however, there is a consistent functional relationship between the number of working hours and their effects on the workers that holds over a great variety of conditions.”

Garbarino (2006) noted that night shiftwork (NSW) negatively affects performance efficiency, health and social relations. “The effects manifest themselves not only as increased accidents’ frequency, but also as sleep disturbances, excessive daytime sleepiness, psychosomatic disorders that may variously interact to configure a ‘shift-lag’ syndrome, with acute and chronic manifestation. Chronic effects increase the risk of psychoneurotic, cardiovascular and gastrointestinal diseases. The effects of NSW on women are much more pronounced because of their reproductive function and family obligations. Recent Italian legislation (1999, 2003) on night-work has essentially recognised it as a new risk factor and has established that workers’ health should be safeguarded through preventive check-ups and regular controls by occupational health physicians. This involves that now occupational health physicians are required to inform workers on coping strategies, and carefully assess health disorders with absolute or relative contraindications. Data from international literature and from our group production are revised and discussed.”

De Raeve, Jansen, and Kant (2007) examined “the longitudinal relationship between transitions in work schedules, workhours and overtime and changes in several self-reported health outcomes (general health, fatigue, need for recovery, and psychological distress).” “[T]ransitions in worktime arrangements were prospectively related to changes in several self-reported health outcomes. Substantial and significant associations were found for transitions in work schedule and the incidence of prolonged fatigue and for the need for recovery among men. Moreover, transitions in workhours affected the need for recovery among men, while they influenced general health and psychological distress among women. Finally, transitions in overtime were significantly associated with the incidence of the need for recovery among both men and women and with the incidence of psychological distress among men only.”

Bambra et al. (2008) undertook a “systematic review (following Quality of Reporting of Meta [QUORUM] analyses guidelines) of experimental and quasi-experimental studies, from any country (in any language) that evaluated the effects on health and work-life balance of organizational-level interventions that redesign shift work schedules.” “Twenty-six studies were found relating to a variety of organizational interventions. No one type of intervention was found to be consistently harmful to workers. However, three types were found to have beneficial effects on health and work-life balance: (1) switching from slow to fast rotation, (2) changing from backward to forward rotation, and (3) self-

scheduling of shifts. Improvements were usually at little or no direct organizational cost. However, there were concerns about the generalizability of the evidence, and no studies reported on impacts on health inequalities.”

Barnes-Farrell et al. (2008) “examined the extent to which several shift characteristics (e.g., shift length, working Sundays) are associated with three aspects of off-shift well-being: work-to-family conflict, physical well-being, and mental well-being.” “The Survey of Work and Time was completed by 906 healthcare professionals located in Australia, Brazil, Croatia, and the USA. Hierarchical multiple regression analyses supported the hypothesis that shiftwork characteristics account for significant unique variance in all three measures of well-being beyond that accounted for by work and family demands and personal characteristics. The patterns of regression weights indicated that particular shiftwork characteristics have differential relevance to indices of work-to-family conflict, physical well-being, and mental well-being.”

1. Working Hours

There is excellent research and development information about shiftwork effects available from the Working Time Society (WTS; www.workingtime.org). This Society was formed in 1999 to:

- Promote research into working time and health, including the impact of working hours and the health, safety and quality of life of those concerned.
- Offer practical advice at the manner in which the various adverse effects of working hours may best be minimized.
- Represent the scientific and professional interests of researchers working in the area of working time and health.
- Provide a forum for researchers in this area to meet and discuss their common research interests and findings, including organizing the approximately biannual International Symposia on Night and Shift Work.
- Disseminate Information regarding the effects of working time on health, safety and quality of life, including the publication of the Shiftwork International Newsletter (SIN).
- Maintain a website to further the various aims of the Society and those of the Scientific Committee on Shiftwork of the Inter-national Commission on Occupational Health (ICOH).
- Collaborate fully with the Scientific Committee on Shiftwork of the International Commission on Occupational Health (ICOH) in pursuing these common aims.

Recent issues of the WTS newsletter and conference abstracts are available for free at the WTS website. The excellent research reports that are summarized in these newsletters are far too numerous to be summarized here. The conference abstracts available electronically include those from meetings in 2003, 2005, and 2009 (Bohle, Takahashi, & Popkin, 2009; Fischer, Rotenberg, & de Castro Moreno, 2003; Jansen, Kerkhof, Koopman, & Witmond, 2005; Bohle, Takahashi, Nakata, & Matsumoto, 2005). These reports are one’s best resource for current research interests and findings concerning interactions among shiftwork, circadian rhythms, health, and sleep. The most reliable findings will, of course, have been published subsequently in peer-reviewed journals and in government technical reports.

Winston (1971) addressed physiological costs and preferences for shift work in terms of the use of industrial capital in poor countries.

Koller et al. (1985) examined “Multiple matched cases of shiftworkers, dayworkers and drop-outs.” “In terms of an overall score (‘Health Score’) in shiftworkers health was found to decrease with age markedly; the difference to dayworkers got significant from the 12th year of work exposure onwards. This finding can be ascribed to a high rate of sleep disturbances and a pronounced reduction of wellbeing (already present in younger workers) as well as to a significant increase in morbidity concerning gastrointestinal and cardiovascular ailments. ... In dayworkers a destabilization of health was found which was marked for the middle age; the health score, however, was still significantly better than that of shiftworkers in all age classes. There was evidence of an excess rate for respiratory illnesses. In drop-outs less adverse conditions of health and wellbeing than in shiftworkers were found. But health was more deteriorated than in dayworkers. Having dropped out of shiftwork means an improvement of gastrointestinal and nervous symptoms; the cardiovascular disorders, however, remain high.”

Kogi and Thurman (1993) noted that relatively few countries had changed their working time legislation, even though new working time patterns had shown some changes in approaches to night and shiftwork. “Prominent trends include (i) the spread of irregular hours of work to different sectors, including services, often as a result of decoupling business hours from individual working hours; (ii) greater flexibility, often in return for shorter hours, in covering operating hours by different individuals; (iii) the appearance of complex combinations of different categories of working time arrangements, such as a combination of full-time semi-continuous shifts and part-time weekend shifts; and (iv) the adoption of a complex process for changes in schemes, incorporating group study and joint planning. Importantly, these trends reflect fundamental changes in the concept of night work (and that of nightworkers). The issues related to these recent trends were apparent in the two-year debate that led to new international labour standards” “The new Convention and Recommendation define ‘nightworker’ to include workers performing a substantial amount of night work. They prescribe a variety of actions to improve the quality of working life of such workers, including measures related to working hours, rest periods, safety and health, transfer to day work, maternity protection, social services, and consultations.”

The National Institute of Occupational Safety and Health published a useful guide called *Plain Language about Shiftwork* (Rosa & Colligan, 1997). Jeppesen and Bøggild (1998) “examined the consideration of health and safety issues in the local process of organizing worktime within the framework of regulations.” They concluded that, in the hospitals studied, “The demands for flexibility in combination with the absence of guidelines and the missing dynamics between the parties involved imply that the handling of health and safety issues in the organization of worktime may be accidental and unsystematic.”

Kogi (1998) reviewed “Changes since the early 1990s in international regulations on night and shift work ... including changes in complex shift systems, greater flexibility, increased female participation in night work and attention to health effects.” “Recent international regulations have focused on (i) a broadened scope of regulatory measures treating both genders equally, (ii) multifaceted protection, and (iii) consultation weighing many aspects of job design. The application of these international regulations depends on national laws and practice, with possible derogations. It calls for local support measures, including (i) guidelines for enterprise-level consultations on shift

schedules, (ii) promotion of health and safety measures, and (iii) participatory strategies for locally adjusted shiftwork arrangements and social support.”

Cruz, Della Rocco, and Hackworth (2000) assessed the extent of health, sleep, and shiftwork adaptation problems experienced by Air Traffic Control Specialists (ATCSs) in the United States who work counterclockwise rapid rotations. “Over half of the sample in this study reported periods of severe fatigue or exhaustion and symptoms of gastrointestinal disturbance typically found among shift workers. Better health and sleep pattern index scores were reported by those who preferred rotating schedules and by those who did not work night shifts. The ATCSs in this sample were relatively young and are required to pass a yearly physical to maintain employment. Thus, this may have resulted in low frequencies of reported medical problems. However, reports of sleepiness, fatigue, and falling asleep seem to indicate that countermeasures for sleepiness at work and on the drive home could benefit ATCSs.”

Proctor, White, Robins, Echeverria, and Rocskay (1996) “examined whether increased overtime work predicts impairment in cognitive performance in the domains of attention, executive function, and mood.” “[I]ncreased overtime was significantly associated with impaired performance on several tests of attention and executive function. Increased feelings of depression, fatigue, and confusion were also associated with increased overtime work. In addition significant interaction effects were observed for job type but not for naphtha exposure.

Miller and Firehammer (2007) observed that the U.S. Navy “currently uses an afloat staffing policy that is calculated using a 70-hour workweek per sailor metric.” “However, this construct fails to factor in an individual sailor’s capacity to sustain performance and is based instead on a notional Navy standard workweek. Part of the inadequacy of the current staffing policy results from its failure to consider an inviolable and basic physiological requirement for adequate sleep and rest for sailors.”

Mason (2009) examined “the total number of hours Sailors actually work in contrast with the [U.S.] Navy Standard Workweek Model.” “The results indicated that 85% of the participants within the study exceeded the 81 hours of available time allotted by the Standard Navy Workweek. On average, Sailors in the current study, excluding officers, worked 9.90 hours per week more than allotted in the Navy Standard Workweek.”

2. Cancer

In 2007, the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) released the following statement:

Epidemiological studies have found that long-term nightworkers have a higher risk of breast cancer risk than women who do not work at night. These studies have involved mainly nurses and flight attendants. The studies are consistent with animal studies that demonstrate that constant light, dim light at night, or simulated chronic jet lag can substantially increase tumour development. Other experimental studies show that reducing melatonin levels at night increases the incidence or growth of tumours.

These results may be explained by the disruption of the circadian system that is caused by exposure to light at night. This can alter sleep-activity patterns, suppress melatonin production, and dysregulate genes involved in tumour development. Among

the many different patterns of shiftwork, those that include nightwork are most disruptive to the circadian system.

The full results of the IARC review were to be published as volume 98 of the IARC Monographs.

Davis, Mirick, and Stevens (2001) hypothesized that “Exposure to light at night may increase the risk of breast cancer by suppressing the normal nocturnal production of melatonin by the pineal gland, which, in turn, could increase the release of estrogen by the ovaries.” They examined data from 813 patients from 1992 to 1995 and 793 controls. “Breast cancer risk was increased among subjects who frequently did not sleep during the period of the night when melatonin levels are typically at their highest. Risk did not increase with interrupted sleep accompanied by turning on a light. There was an indication of increased risk among subjects with the brightest bedrooms. Graveyard shiftwork was associated with increased breast cancer risk, with a trend of increased risk with increasing years and with more hours per week of graveyard shiftwork.”

Schernhammer et al. (2001) “examined the relationship between breast cancer and working on rotating night shifts during 10 years of follow-up in 78,562 women from the Nurses' Health Study,” 1988 through 1998. “We observed a moderate increase in breast cancer risk among the women who worked 1-14 years or 15-29 years on rotating night shifts. The risk was further increased among women who worked 30 or more years on the night shift.” This group also “examined the relationship between working rotating night shifts and the risk of colorectal cancers among female participants” in the same Study (Schernhammer et al., 2003). The data suggested that “working a rotating night shift at least three nights per month for 15 or more years may increase the risk of colorectal cancer in women.” They went on to examine “interrelationships of night work, urinary melatonin levels, and levels of plasma steroid hormones in women” using data from the same Study (Schernhammer et al., 2004). “We found significantly increased levels of estradiol after longer durations of night work. We observed a significant inverse association between increasing number of nights worked within the 2 weeks preceding urine collection and urinary melatonin levels, but no association of recent night work with estradiol.” They concluded that “A single morning urinary melatonin measurement is a reasonable marker for long-term melatonin levels among pre-menopausal women. Women who work on rotating night shifts seem to experience changes in hormone levels that may be associated with the increased cancer risk observed among night-shift workers.”

Kennaway, Butler, and Tilley (2005) noted that “Circadian rhythms are regulated by a panel of specific transcription factors, called clock genes, and our current understanding of endogenous cellular rhythmicity is that both positive and negative feedback cycles of clock genes drive the expression of a growing list of other transcription factors and functional genes.” Thus, they argued, “It is possible that disruption of circadian control systems, which maintain normal cell function, could lead to malignant transformation into cancer cells. This concept is supported by recent findings that tumors grow faster in mice rendered arrhythmic by destruction of the suprachiasmatic nucleus, the body's circadian clock. Furthermore, mice carrying a mutation in one of the core clock genes, *per2*, have disrupted circadian rhythmicity and are cancer prone, possibly due to permanent up-regulation of clock-controlled oncogenes.” “As the patterns of expression were highly tissue-specific, it is critical to determine which clock and clock-controlled genes are expressed in mammary tissue and potentially contribute to the increased risk of breast cancer associated with shift work.”

Megdal, Kroenke, Laden, Pukkala, and Schernhammer (2005) “conducted a systematic review and meta-analysis of observational studies to assess the effects of night work on breast cancer risk” using data from MEDLINE from 1960 to 2005 and other sources. They concluded that “Studies on night shift work and breast cancer risk collectively show an increased breast cancer risk among women.”

Schernhammer, Kroenke, Laden, and Hankinson (2006) “studied the relation between rotating night shift work and breast cancer risk.” “Women who reported more than 20 years of rotating night shift work experienced an elevated relative risk of breast cancer compared with women who did not report any rotating night shift work. There was no increase in risk associated with fewer years of rotating night work.” The same group examined the relationships of lifestyle factors other than night work and endogenous sex steroid hormones with melatonin levels (Schernhammer, Kroenke, Dowsett, Folkard, & Hankinson, 2006). “[H]igher age, BMI, and heavy smoking were significantly related to lower levels of melatonin, whereas parity was significantly associated with higher aMT6s levels. Melatonin levels may be one mechanism through which these factors influence the development of cancer, but more studies are needed to elucidate these mechanisms definitively.”

Davis and Mirick (2006) reviewed several studies conducted in Seattle to “investigate the effects of factors that can disrupt circadian rhythm and alter normal nocturnal production of melatonin and reproductive hormones of relevance to breast cancer etiology.” “Studies completed to date have found: (1) an increased risk of breast cancer associated with indicators of exposure to light-at-night and night shift work; and (2) decreased nocturnal urinary levels of 6-sulphatoxymelatonin associated with exposure to 60-Hz magnetic fields in the bedroom the same night, and a number of other factors including hours of daylight, season, alcohol consumption and body mass index. A study was underway to “determine whether working at night is associated with decreased levels of urinary 6-sulphatoxymelatonin, and increased urinary concentrations of the reproductive hormones ..., and to elucidate characteristics of sleep among night shift workers that are related to the hormone patterns identified. A proposal is under review to extend these studies to a sample of healthy men to investigate whether working at night is associated with decreased levels of urinary 6-sulphatoxymelatonin, and increased concentrations of urinary cortisol and cortisone, urinary levels of a number of androgen metabolites, and serum concentrations of a number of reproductive hormones. Secondly, the proposed study will elucidate characteristics of sleep among night shift workers that are related to the hormone patterns identified, as well as investigate whether polymorphisms of the genes thought to regulate the human circadian clock are associated with the ability to adapt to night shift work. It is anticipated that collectively these studies will enhance our understanding of the role of circadian disruption in the etiology of cancer.”

Haus and Smolensky (2006) noted that “A phase shift as experienced in night and rotating shift work involves desynchronization at the molecular level in the circadian oscillators in the central nervous tissue and in most peripheral tissues of the body.” “The implications of the pathophysiology of phase shift are discussed for long-term health effects and for the design of ergonomic work schedules minimizing the adverse health effects upon the worker.” Kennaway (2007, 2008) used a mouse model to “examine the effects of shiftwork on the expression of genes that are directly involved in the genesis and progression of breast cancer.” A final report is pending.

Franzese and Nigri (2007) “selected 5 international study, published on well known journals and based on large numbers of subjects, and we evaluated them in order to define a state of the art” on research concerning the relationship between night work and breast cancer. “[W]e conclude that

nurses who frequently attend night shifts should undergo strict and periodical breast cancer screening, since the risk is significantly increased in this population.”

Melatonin has several oncostatic properties, including possible anti-estrogenic and anti-aromatase activity, and seems to be linked with fat metabolism. Night workers have lower levels of melatonin, which may predispose them to develop cancer. Endometrial cancer risk is influenced significantly by hormonal and metabolic factors; therefore, we hypothesize that night workers may have an increased risk of endometrial cancer. Of the 121,701 women enrolled in a prospective cohort study, 53,487 women provided data on rotating night shift work in 1988 and were followed through on June 1, 2004. A total of 515 women developed medical record-confirmed invasive endometrial cancer. We used Cox regression models to calculate multivariate relative risks (MVRs), controlling for endometrial cancer risk factors. Women who worked 20+ years of rotating night shifts had a significantly increased risk of endometrial cancer [MVR, 1.47; 95% confidence interval (95% CI), 1.03-1.14]. In stratified analyses, obese women working rotating night shifts doubled their baseline risk of endometrial cancer (MVR, 2.09; 95% CI, 1.24-3.52) compared with obese women who did no night work, whereas a non-significant increase was seen among non-obese women (MVR, 1.07; 95% CI, 0.60-1.92). Women working rotating night shifts for a long duration have a significantly increased risk of endometrial cancer, particularly if they are obese. We speculate that this increased risk is attributable to the effects of melatonin on hormonal and metabolic factors. Our results add to growing literature that suggests women who work at night may benefit from cancer prevention strategies.

Viswanathan, Hankinson, and Schernhammer (2007) noted that “Melatonin has several oncostatic properties, including possible anti-estrogenic and anti-aromatase activity, and seems to be linked with fat metabolism.” They found that “Women working rotating night shifts for a long duration have a significantly increased risk of endometrial cancer, particularly if they are obese. We speculate that this increased risk is attributable to the effects of melatonin on hormonal and metabolic factors.”

Cornélissen et al. (2008) reviewed “studies involving shifts in schedule implemented at varying intervals in unicells, insects and mammals, including humans.” “Results indicate the desirability to account for a broader-than-circadian view. They also suggest the possibility of optimizing schedule shifts by selecting intervals between consecutive shifts associated with potential side-effects such as an increase in cancer risk.”

Kolstad (2008) reviewed “the role of nightshift work in the risk of breast cancer or other cancers.” “There were indications of a long-term effect of nightshift work (more than 20-30 years), but the number of positive studies was small. In addition, they were all conducted among nurses, and the risk estimates were only moderately increased. This situation makes the results sensitive to bias, chance, and confounding.” “There is limited evidence for a causal association between nightshift work and breast cancer, while there is insufficient evidence for prostate cancer, colon cancer, and overall cancer.” Erren, Pape, Reiter, and Piekarski (2008) provided a meta-analysis of 30 epidemiological studies. They observed that chronodisruption “can play a causal role for cancer growth and tumor progression in animals. “Moreover, flight personnel and shift workers exposed to chronodisruption may have increased breast and prostate cancer risks.” “The challenge for future epidemiological investigations of the biologically plausible links between chronodisruption and human cancers is to conduct studies which appreciate details of transmeridian traveling, of shift work and of covariates for the development of the diseases.”

Nagata et al. (2008) “assessed associations among concentrations of serum estrogen and androgen and the principal metabolite of melatonin in urine, 6-sulfatoxymelatonin, and exposure to light at night” in 206 postmenopausal Japanese women. The data suggested that “exposure to light at night has implications for the risk of breast cancer in postmenopausal women. However, the potential role of melatonin as an intervening factor between light exposure at night and the serum concentrations of estrogen was equivocal.”

Erren et al. (2009) participated in a 2007 IARC panel that “systematically evaluated epidemiologic, experimental, and mechanistic data and concluded that shift work that involves circadian or chronodisruption is probably carcinogenic in humans.” “In view of the possible scope of the problem—shift work is widespread and unavoidable on one hand and breast cancer and prostate cancer, which may be causally associated with chronodisruption, are epidemic worldwide on the other—German representatives of science and occupational medicine discussed the experimental and epidemiologic background and possible implications of the challenge identified by the International Agency for Research on Cancer (IARC) at a colloquium in Cologne in September 2008. This overview summarizes the key ideas presented at the Cologne Colloquium and offers 10 theses concerning the need for targeted studies and the necessity to develop possible means of prevention.” However, Erren and Reiter (2009) noted that “neither the IARC information available so far nor the general literature provides a clear definition of what the critical component in the postulated chain of causation, namely circadian disruption, is.” They offered their definition of chronodisruption (CD), operationalized in “research which addressed the putative links between shift-work, time-zone-travel and human cancers independently of the IARC and led to similar causal interpretations.” As a basis for further research in this area with possible high relevance for public health, we:

(i) elaborate our definition of CD, with melatonin being a key biological intermediary, by putting critical disruptions, and the resulting disorder, of circadian clocks, biological rhythms and circadian organization into thematic and historical context with Colin Pittendrigh’s insights almost half a century ago; (ii) provide material on ‘what are chronodisruptors?’ and (iii) pose a key question which needs to be answered by and for experimental and epidemiological CD research.”

Viswanathan and Schernhammer (2009) noted that “the antineoplastic action of melatonin arises through many different mechanisms, including melatonin’s antioxidant, antimitotic, and antiangiogenic activity, as well as its ability to modulate the immune system and alter fat metabolism.” “Melatonin interacts with membrane and nuclear receptors, and may be linked to the regulation of tumor growth. Of particular relevance to breast cancer risk, melatonin may also block the estrogen receptor ERalpha and impact the enzyme aromatase, which produces estradiol. A growing number of epidemiologic studies have evaluated the relationship between night shift work as well as how varying duration of sleep affects peak melatonin secretion at night. While the studies demonstrate lower nightly melatonin levels in night workers, the evidence for an association between sleep duration and melatonin production is less clear. Similarly, both case-control and prospective cohort studies have consistently linked night shift work with breast cancer risk and, more recently, endometrial cancer—another tumor highly sensitive to estrogens. While, to date, the evidence for an association between sleep duration and breast cancer risk is less convincing, overall, there is increasing support for a potentially important link between melatonin and breast cancer risk and perhaps the risk of other tumors.”

Kantermann and Roenneberg (2009) noted that “The hormone melatonin is often considered to be a causal link between night shift and tumor development.” “The underlying ‘light-at-night’ (LAN) hypothesis is based on the following chain of arguments: melatonin is a hormone produced under the control of the circadian clock at night, and its synthesis can be suppressed by light; as an indolamine, it potentially acts as a scavenger of oxygen radicals, which in turn can damage DNA, which in turn can cause cancer. ... We revisit the arguments of the LAN theory and put them into perspective regarding circadian physiology, physical likelihood (e.g., what intensities reach the retina), and potential risks, specifically in non-shiftworkers.”

3. Cardiovascular and Respiratory

Colquhoun (1988) recorded heart rate “at regular intervals during the course of 8-hour sessions of simulated sedentary shift work performed for 12 consecutive days.” “In all groups heart rate fell during the pre-break period, but rose after the break in response to the meal. This pattern remained constant over the 12-day period in the morning and day shift groups, but in the night shift group a progressive rise in the general level of the readings, caused mainly by the adjustment of the circadian rhythm to the altered sleep/wake cycle, was accompanied by systematic changes in the extent of both the pre-break fall and the post-meal rise. Comparison with the results of a control study of 24-hour variation in base heart rate suggested that differential responses to the meal observed in the three shift groups may have been due, at least in part, to differences in their personality make-up.”

Knutsson, Åkerstedt, and Jonsson (1988) examined 361 shift workers and 240 day workers “with respect to some major risk factors for coronary artery disease. “A higher proportion of shift workers smoked (54 versus 39%). Shift workers also had significantly higher levels of serum triglycerides (1.61 versus 1.43 mmol/l). Body mass index and the blood pressure and total cholesterol levels did not differ between the groups. Multiple regression analyses demonstrated that shift work was significantly related to serum triglyceride levels also when age, smoking, body mass index, and other variables were controlled for.” Knutsson (1989) then conducted a prospective study of 25 male shift and day workers for six months. The data “indicated that the diet of shift workers might be responsible for changes in the ratio between apoB and apoA-1, a ratio which is related to risk of coronary disease. The analyses of spontaneous changes in the diet showed that the shift workers tended to decrease the intake of dietary fibre and increase the intake of saccharose [sucrose]. The change in the ratio between apoB and apoA-1 correlated inversely with the change in intake of dietary fibre. It is concluded that spontaneous changes in the diet of shift workers might be responsible for changes in serum lipoproteins. Three major disease pathways from shift work to CHD are proposed: (i) disturbed physiological rhythm and/or a collision between the circadian rhythm and myocardial performance, (ii) changes in behaviour, and (iii) disturbed sociotemporal rhythmicity, which might lead to distress reactions.”

Chan, Gan, and Yeo (1933) studied health complaints, blood pressure, sleep and sickness absence experience in 308 female electronics workers, 253 on permanent and 55 on rotating schedules, compared to 75 day workers. “No significant differences in prevalence of hypertension were noted.” Goto et al. (1994) investigated the “effects of shift work on circadian BP variation” with ambulatory, 24-hour monitoring. “During sleep, BP was lower and the heart rate was slower in the day shift (night sleep) perhaps because of deeper sleep than during daytime sleep associated with the night

shift. During work, BP was identical but the heart rate was significantly slower during the night shift.”

Nakamura et al. (1997) looked for an “association between shift work and risk factors for coronary heart disease (CHD) in Japanese male blue-collar shift workers.” “[T]hree-shift workers had higher risks of CHD than day workers, which was characterized by higher levels of serum total cholesterol and tendency to central obesity.” Tenkanen *et al.* studied the “risk of coronary heart disease (CHD) in shift work and the possible pathways for CHD in industrial workers ... along with the importance of shift work as an occupational class gradient of CHD risk” (Tenkanen, Sjöblom, Kalimo, Alikoski, & Härmä, 1997). “When all the shift workers were compared with all the day workers, the relative risk of CHD was 1.5 when only age was adjusted for and 1.4 when life-style factors, blood pressure, and serum lipids were also adjusted for.”

Adams, Roxe, Weiss, Zhang, and Rosenthal (1998) sought to determine whether blood pressure (BP) and heart rate variability (HRV) of the emergency physician are affected during a night shift in the emergency department. They also used ambulatory, 24-hour monitoring, and twelve participants completed the study. “An elevation of mean DBP (5.5 mm) during night shift activity was seen. A trend toward elevation of SBP, MAP, and HR was discernible. HRV measures indicated a significant relative increase in sympathetic vs parasympathetic tone and an increase in HR of pre-work and work compared with post-work. Dysrhythmias observed included sinus tachycardia, sinus bradycardia, sinus pause, atrial premature beats, atrial couplets and triplets, supraventricular tachycardia, and premature ventricular contractions. The elevation of DBP during a night shift suggests that these patterns of BP variability are activity- or stress-related rather than a result of a true diurnal variation. HRV analysis suggests that sympathetic tone is heightened both before work and during work.”

Yamasaki et al. (1998) evaluated the “effects of shift work and race/ethnicity on the diurnal rhythm of blood pressure and urinary catecholamine excretion of healthy female nurses, 37 African American women and 62 women of other races” using ambulatory, 24-hour monitoring. “Of African Americans, 79% who were working evenings or nights and 32% working day shifts were nondippers (<10% drop in systolic pressure during sleep), whereas only 29% of others working evening+night and 8% working day shifts were nondippers. ... After controlling for work shift and race/ethnicity, we determined that longer sleep times predicted less dipping (absolute and relative) in blood pressure. Urinary norepinephrine and epinephrine were higher during work than non-work in both racial groups of day shift workers, but in evening+night shift workers the difference was small and in the opposite direction. These results indicate that being African American and working evening or night shifts are independent predictors of nondipper status. Higher sleep blood pressure may contribute to the known adverse effects of shift work.”

Ohira et al. (2000) “examined the effects of rotating shift work on blood pressure in a comparison of ambulatory blood pressure and long-term changes in blood pressure between shift and day workers.” “On the average, sleep time was shorter and the anger-in (i.e., anger suppressed) score was higher for the shift workers than for the day workers, but body mass index and alcohol intake did not differ between the 2 groups. Even after adjustment for these co-variables, the mean systolic blood pressure during the 24-hour, awake, and work periods were higher among the shift workers than among the day workers. The 24-hour standard deviations of the systolic blood pressures were also higher for the shift workers than for the day workers. Among the shift workers, but not among the day

workers, a significant long-term increase was observed in systolic blood pressure measured in the annual surveys.”

Bøggild, Burr, Tüchsen, and Jeppesen (2001) “examined whether shift work is associated with other work environment factors related to heart disease in a random sample of the population” using data from 5,940 employees in the Danish Work Environment Cohort Study from 1990. They concluded that “shift work was found to be associated with other work environment factors suspected to cause heart disease.” Ha, Kim, Park, and Chung (2001) examined blood pressure (BP) and heart rate variability (HRV) of 134 male workers, who worked 8-hour shifts with rapid rotation of shifts at 3-day intervals. “In the multivariate analysis adjusted by age, job strain, shift, circadian rhythm and smoking, the blood pressure showed significantly increasing trends according to shiftwork duration in both the systolic and diastolic BP. The heart rate variability also showed a significantly decreasing trend according to the shiftwork duration in both the parasympathetic and sympathetic functions ($p < 0.05$). These results suggest that there are negative health effects arising from shiftwork on the cardiovascular system.”

Holmes et al. (2001) examined “the effects of one week of simulated night shift on cardiac sympathetic (SNS) and parasympathetic (PNS) activity” in 10 healthy during one week of night shift. “Night shift did not influence sleep quality, but reduced sleep duration by a mean of 52 ± 29 min. One week of night shift evoked a small chronic sleep debt of $5 \text{ h } 14 \pm 56$ min and a cumulative circadian phase delay of $5 \text{ h } \pm 14$ min. Night shift had no significant effect on mean HR, but mean cardiac SNS activity during sleep was consistently higher and mean cardiac PNS activity during sleep declined gradually across the week. These results suggest that shiftwork has direct and unfavourable effects on cardiac autonomic activity and that this might be one mechanism via which shiftwork increases the risk of cardiovascular disease. It is postulated that sleep loss could be one mediator of the association between shiftwork and cardiovascular health.”

Kario et al. (2002) tested “the hypothesis that cardiovascular reactivity to acute stress and/or delayed recovery predicts greater diurnal BP variation (i.e., a lower sleep/awake BP ratio).” They “studied the relationship of diurnal BP variation (assessed by ambulatory BP monitoring) to mental stress (mental arithmetic and anger recall tasks) and physical stress (treadmill)-induced cardiovascular reactivity and recovery in 87 female nurses who worked different shifts.” “[C]ardiovascular reactivity triggered by psychological and physical stress in the laboratory may be a weak, but significant, determinant of diurnal BP variation; in addition, work shift (day or night) appears to moderate the relationship between these two pressor mechanisms.”

Hirose (2005) reviewed his “research findings on sleep and health for shift workers at a bakery and a dish factory.” “Our medical examinations revealed that rises in blood pressure (BP) were frequently observed in male bakery workers on the fixed night shift. They took a two-hour nap from 1:00 to 3:00 during the night shifts according to our advice. As a result, their diastolic BP significantly decreased in subsequent years. Women working shifts before 3:00 at a dish factory seemed to show more sleep disturbance, higher daytime sleepiness, and more fatigue than those working shifts from 3:00. Total sleep hours taken during the daytime was similar between two groups. Among the dish factory workers who switched to midnight or night shifts, 70% reported slow recovery from fatigue and 30% felt deteriorated health. These women also reported increased efforts to obtain a deep sleep, probably making up for shortened sleep.”

Tüchsen, Hannerz, and Burr (2006) estimated “the risk of circulatory disease in a prospective follow up of a representative sample of gainfully employed Danes, considering known or suspected confounding factors.” They examined data for 5,517 people who were followed up for all hospital treatments due to circulatory diseases from 1991 to 2002 inclusive; 927 men and women who worked nights, evenings, or other non-day shifts were compared to 4,579 day workers. “Non-day workers compared to day workers had a relative risk (RR) for all circulatory diseases of 1.31. ... For a subgroup of workers with at least three years' seniority, the RR was 1.40.”

Su et al. (2008) determined “the hemodynamic effects of 12-hour (12-h) shifts, and changes in blood pressure (BP) and heart rate variability (HRV) during 36 h rest time following 12-hour shifts” with ambulatory monitoring of 15 male shift workers recruited from a semiconductor factory. “Results showed that 12-hour night shift work gave a persistently elevated systolic and diastolic BP (SBP and DBP) and HR, and decreased HRV compared to 12-hour day shift work with the corresponding resting time. In addition, there was delayed SBP and DBP recovery on the first 12-hour rest time in night shift workers, which was further demonstrated on the second 12-hour rest time after adjustment for possible confounders through mixed models.”

Copertaro, Bracci, Barbaresi, and Santarelli (2008a) examined “the effectiveness of three screening methods and plasma hyperhomocysteinemia, an independent risk factor, in assessing the risk of CVD in 147 healthcare providers doing daytime or *rotational* shift work.” The increased risk of CVD associated with shift work was related to the greater incidence of metabolic syndrome among these workers.

Nabe-Nielsen, Garde, Tüchsen, Hogh, and Diderichsen (2008) examined differences between future shift workers and future day workers as regards cardiovascular risk factors before they began different work schedules and the differences that remained after control for socio-demographic factors and general self-efficacy.” “2,870 newly educated social and health care workers filled out a questionnaire a few weeks before finishing their formal training and again 1 year after graduation.” “Compared with future day workers, fixed evening or fixed night workers already smoked more before they began shift work. Being an ex-smoker was significantly associated with two- or three-shift work including night work. These results indicate that smoking status should not solely be treated as a mediator between some variants of shiftwork schedules and cardiovascular diseases but should also be considered a confounder.”

Lo, Liao, Hwang, and Wang (2008) performed repeated ambulatory blood pressure (BP) monitoring during their workdays and following day off on 16 young female nurses working rotating shifts and six working the regular day shift. “Shift work is significantly associated with BP and possibly dipper/nondipper status in young female nurses. Except for those working night shifts, BP levels returned to baseline the off-duty day after day shift.”

4. Gastrointestinal

Angersbach et al. (1980) conducted a retrospective cohort study in a firm in the chemical industry using the sick records of 370 shift workers in a 12-hour shift *rota* and of 270 day workers from 1966 to 1977. “Significantly more shift workers than day workers consulted the occupational health services about gastrointestinal complaints than day workers. Shift workers had more frequent gastrointestinal diseases than day workers and more severe ones such as peptic ulcers.

Gastrointestinal diseases were more frequent in the following groups of the shift workers: Young (21 to 25 years) and unmarried subjects, heavy smokers and subjects with a past history of gastrointestinal diseases.”

Koller et al. (1985) observed that shiftworkers' health was found to decrease with age markedly and that this finding could be ascribed to, among other things, a significant increase in morbidity concerning gastrointestinal ailments.

Tarquini, Cecchettin, and Cariddi (1986) studied serum gastrin (G) and group I pepsinogen (PG1) in five adult male foundry shift workers over a month's span during a weekly rotating shift schedule. Six adult, day-working males acted as controls. Shiftwork was associated with “a prominent change in the gastrin/acidopepsin secretion system.”

Segawa et al. (1987) compared the prevalence of peptic ulcer disease among 11,657 shift workers and daytime workers. “The prevalence of gastric and duodenal ulcers was higher with shift workers than daytime workers.”

Higashi, Sakurai, Satoh, and Toyama (1988) studied “1982 data for 26,324 male manufacturing workers including 13,472 shift workers, incidences (inception rate) of diseases that caused absence and days lost due to them” to evaluate the effect of shift work. “The incidence of peptic ulcer was significantly higher (rate ratio=1.6) among shift workers as compared with day workers. The incidences of days lost due to other diseases in shift workers were almost equal to or lower than those in day workers.”

Vener, Szabo, and Moore (1989) proposed “a theoretical framework to explain the altered physiological states that produce the GI symptom complexes or diseases that are related to shift work, notably ulcers.” This framework is based on an integration of the literature on (1) central nervous system (CNS) control and integration of circadian rhythms and (2) shift work and GI symptoms/disease. CNS structures relevant to rhythm control in mammals include the suprachiasmatic nucleus and the pineal gland. CNS control of adrenal function and of gastric function in health and disease are reviewed.”

Mazzetti di Pietralata et al. (1990) “conducted a clinical and anamnestic [retrospective] investigation on digestive disturbances and alimentary habits of shift-workers comparing them with non shift-workers.” “The most interesting result of this study is represented by the confirmation of statistical significance among the larger incidence percentage of digestive disturbances between shift and non shift-workers. Moreover, statistical differences have been remarked among the different groups of shift-workers examined. For these reasons the authors believe that shift-work is *per se* responsible of digestive diseases in the workers engaged to it and they also think that it is very important to distinguish the kind of shift work which may produce environmental, psychological and motivational differences.”

Laitinen (1997) provided guidelines for shiftworker diet to help avoid gastrointestinal problems.

Pitsopoulos and Greenwood (2002) noted that “The measures of gastrointestinal and cardiovascular health in The Standard Shiftwork Index (SSI; Barton, Costa, Smith, Spelten, Totterdell, & Folkard, 1995) purport to measure the frequency of 19 related symptoms using a 4-point rating scale.” They “examined the relationship between frequency ratings of 11 gastrointestinal and 8 cardiovascular symptoms made on the SSI 4-point scale, and ratings of the same symptoms made on an alternative 9-

point rating scale.” “[T]he correlations between the two response formats were not high for any of the 11 gastrointestinal or 8 cardiovascular symptoms.”

Caruso, Lusk, and Gillespie (2004) examined “the relationship between work schedules and GI symptoms, medications, and diagnoses” using a cross-sectional survey of 343 U.S. auto factory workers. “The evening shift was associated with more GI symptoms and GI diagnoses. Unexpectedly, more consistent work times were associated with having a GI diagnosis. As schedule variability increased the probability of GI medication use increased in low noise exposure.”

Pietroiusti et al. (2006) evaluated the question of “whether shift work is associated with an increased rate of peptic ulcer in infected workers,” assessing 247 day-time workers and 101 shift workers. The prevalence of duodenal ulcer was significantly higher in shift workers than in day-time workers.”

Zhen Lu, Ann Gwee, and Yu Ho (2006) compared “the frequency and severity of bowel disturbances between rotating shift and regular day nurses” and examined the question of “whether functional bowel disorders (FBD) were related to sleep disturbances.” “Although 22 out of 58 rotating shift nurses (38%) had FBD, only 12 out of 60 regular day nurses (20%) had it. The mean FBD symptom score, sleep disturbance score and anxiety score were all significantly higher among the rotating shift nurses. FBD symptom scores were positively correlated with the sleep disturbance, anxiety, depression, well-being, fatigue, and somatic pain scores. Sleep disturbance, decreased well-being, anxiety, and somatic pain were independent predictors of FBD symptoms.”

Çelik, Veren, and Ocakci (2008) examined “the effect of self-reported work life and nutritional habits of intensive care unit nurses in the incidence of gastrointestinal complaints.” “This study of 110 nurses found that long work hours at night and incorrect eating and drinking habits affect their gastrointestinal system.”

Yildiz and Esin (2009) examined the prevalence of gastrointestinal and cardiovascular symptoms among nurses. “Compared with results in similar studies, the nurses’ gastrointestinal and cardiovascular symptoms scores in our study are quite high. The regression model shows that gastrointestinal symptoms are most prevalent in the 20-30-year-old age group and the cigarette-smoking group.”

5. Hormones and Metabolism

In the heyday of “stress” research, Froeberg, Karlsson, and Levi (1972) investigated “inter-shift differences and changes from the beginning to the end of shift-weeks on different shifts with regard to catecholamines, diuresis, and self-ratings of fatigue and other mood variables.” “The main hypotheses were that catecholamine excretion, diuresis and subjective ‘arousal’ are lower during the night shift than during the day shifts, these differences decrease after a few days on the same shift, i.e. an ‘adaptation’ occurs, and individuals who have favourable attitudes towards shift work and the *rota* system do ‘adapt’ to a greater extent than those with unfavourable attitudes.”

Nearly two decades later, Knutson, Andersson, and Berglund (1990) assessed “changes in diet and serum lipoproteins in shift workers.” “Twelve shift workers and 13 day workers were examined before employment and after six months at work. Total cholesterol and serum triglycerides did not change significantly. In both groups a decrease in systolic blood pressure was observed. The ratio between apoB and apoA-1 lipoproteins increased by 18% in shift workers compared with 5% in day

workers. The change in the ratio between apoB and apoA-1 lipoproteins showed a significant inverse correlation with the change in intake of dietary fibres.”

Fujiwara, Shinkai, Kurokawa, and Watanabe (1992) examined “the temporal changes in circadian rhythm of oral temperature, heart rate, serum cortisol and urinary catecholamines levels due to experimental short-term shifts.” “[T]he phases of circadian rhythms were delayed to different degrees in the evening shifts with a minimum of about 1 h for oral temperature and a maximum of about 4 h for urinary free noradrenaline. The corresponding phase delays were larger in the night shift for oral temperature (about 3 h), resting heart rate (about 5 h) and urinary free noradrenaline (about 13 h); the diurnal variations of serum cortisol and urinary free adrenaline were greatly modified, and their circadian rhythmicities disappeared, indicating that the normal circadian phase relations of these variables were disrupted more by the night shift. The comparison of chronograms and correlation analyses revealed that the 4-hour mean heart rate and urinary free noradrenaline were largely affected by rest-activity level in connection with shifts, while the resting heart rate and urinary free adrenaline were less affected. On the other hand, the sleep factor (time of onset and/or period) seemed to be more potent in modifying the circadian rhythm of serum cortisol, especially with the night shifts.”

Romon et al. (1992) assessed relationships “between shift work and serum lipid levels.” “Shift workers had significantly higher levels of serum triglyceride. Cholesterol and HDL cholesterol levels were similar for the two groups. There was no difference in energy and nutrient intake, but day workers had a higher alcohol intake. Multivariate analysis conducted with triglycerides as dependent variable and shift work, BMI, smoking, age, leisure time physical activity level, energy intake, and alcohol intake as independent variables confirmed that shift work has a significant explanatory power for triglyceride levels.”

Motohashi (1992) investigated “the relationship between internal desynchronization and clinical intolerance to shift work” in seven shift-working ambulance personnel.” The peak time of salivary cortisol rhythm during a twenty-four hour shift was phase-advanced as [one subject who was] intolerant to shift work showed apparently an atypical circadian pattern of salivary cortisol with an abnormal peak at 21.00 h. ... The clinical implication of impairment of salivary cortisol rhythm remains to be further investigated.”

Shinkai, Watanabe, Kurokawa, and Torii (1993) examined “the validity of salivary cortisol for monitoring circadian rhythm variation in adrenal activity during shiftwork.” “The salivary cortisol showed relatively low levels, the 2-day mean value being 3.1%-3.3% that of serum total cortisol through all shifts. Significant differences in the serum to saliva cortisol ratios were noted among shifts and subjects. When expressed as a relative percentage of a 2-day mean value, however, salivary cortisol paralleled the modified circadian profiles of serum total cortisol of the evening and night shifts, with no significant time lag and no difference in magnitude. The cosinor analysis supported this finding. Thus, salivary cortisol appears to be an excellent measure for monitoring circadian rhythm variation in adrenal activity in healthy individuals during shiftwork.”

Hakola, Härmä, and Laitinen (1996) examined “the adjustment of sleep-wakefulness and other circadian rhythms during consecutive night shifts” and “the effect of gender on the adjustment to night work” in a laboratory setting. “The circadian rhythm of body temperature, salivary cortisol, and time in bed changed significantly between the workshifts, but no differences were found between the men and women in the circadian adjustment of the physiological variables to night work.”

Spiegel, Weibel, Gronfier, Brandenberger, and Follenius (1996) studied eight workers “to determine whether the [prolactin] PRL rhythm is adapted to their rest-activity schedule and whether this provides evidence in favor of an endogenous clock-driven component.” “For the two groups of subjects a transient PRL peak, similar in size and time of occurrence, was observed during the night. Melatonin, a strong marker of the primary circadian oscillator, displayed a phase shift that differed widely among night workers. Body temperature, on the other hand, was found to be more regularly adapted despite the persistence of a small decrease or leveling off during the night. Although no relationship was found between the melatonin increase and the nocturnal PRL peak, a concomitance with this transient temperature decrease could be demonstrated. The persistence of this PRL peak in night workers raises the question of its significance.”

Weibel, Spiegel, Follenius, Ehrhart, and Brandenberger (1996) “submitted 11 night workers and 11 day-active subjects to a 10-min blood sampling procedure during their usual sleep-wake cycle, permitting a precise determination of circadian and ultradian cortisol variations.” “In night work, the usual shift of 8 h in the sleep period was associated with a distortion of the normal 24-hour cortisol rhythm. The acrophase exhibited a shift of approximately 6.5 h, whereas the quiescent period, abruptly interrupted by a large peak, underwent a shift of only 3 h and lasted for approximately 5 h, as in day-active subjects. Slow-wave sleep and sleep onset occurred during periods of low or decreasing cortisol secretory rates, whereas awakenings were associated with an increase in cortisol secretory rates. These results revealed that the circadian system of night workers only partially adapts to night work and that adaptation processes rely on an internal dissociation of the markers of the cortisol pattern, without disturbing the processes that couple cortisol release and specific sleep stages.”

Hampton et al. (1996) investigated “postprandial responses to a mixed meal in simulated shift work conditions.” “Nine normal healthy subjects (six males and three females) were studied on two occasions at the same clock time (1330 h) [for six hours] after consuming test meals.” “Significantly higher postprandial glucose responses (total AUC) were observed after the phase shift than before. No significant difference was observed when the first 2 h of each response was compared, but significantly higher glucose levels were observed in the last 4 h of the study after the phase shift than before. Similar results were obtained for insulin. No differences were observed in postprandial plasma GIP and GLP-1 responses before and after the phase shift. Postprandial circulating lipid levels were affected by phase shifting. Peak plasma TAG levels occurred 5 h postprandially before the phase shift. Postprandial rises in plasma TAG were significantly delayed after the phase shift and TAG levels continued to rise throughout the study. Plasma postprandial NEFA levels fell during the first 3 h both before and after the phase shift. Their rate of return to basal levels was significantly delayed after the phase shift compared with before. This study demonstrates that a simulated phase shift can significantly alter pancreatic B-cell responses and postprandial glucose and lipid metabolism.” Subsequently, this group studied twelve healthy subjects on three occasions at the same clock time (1330 h), but at different body clock times (Ribeiro, Hampton, Morgan, Deacon, & Arendt, 1998). “In contrast with a previous study with a high-fat pre-meal, postprandial glucose and insulin responses were not affected by the phase shift. However, basal plasma NEFAs were lower immediately after the phase shift.”

Weibel, Follenius, Spiegel, Gronfier, and Brandenberger (1997) investigated “the degree of adaptation [to night work] of the growth hormone (GH) rhythm, considered to be mainly sleep-

dependent, but for which a weak circadian drive has also been suggested.” “Eleven night workers were studied during their usual sleep-wake cycle, and two groups of 11 normally day-active subjects, sleeping once during the night and once after an 8-hour sleep delay, were used as control groups. ... The total amount of GH secreted during the 24 h did not differ between the three groups and the main secretory episode occurred, in most cases, during the first half of the sleep period. In night sleepers and night workers the enhanced amount of GH secreted at that time was followed by a significantly lower amount secreted during the second part of the sleep period. For night sleepers, an enhanced GH pulse frequency was found at the beginning of sleep, whereas for night workers and day sleepers the pulses were distributed more randomly throughout the nycthemeron. After an abrupt sleep shift, all the subjects displayed a GH pulse at the usual time of early sleep, but such a pulse was present in only 8 of 11 night workers. Thus the amount of GH secreted between 23:00 h and 03:00 h in day sleepers did not differ significantly from that observed in night sleepers, whereas it differed for night workers.”

Hennig, Kieferdorf, Moritz, Huwe, and Netter (1998) studied “the size of changes and the time point of ... changes in biological rhythms during night-shift and whether they are associated with tolerance to shiftwork.” “[A] sample of 24 night-shift workers was investigated in a cardiac emergency unit for seven nights. Saliva samples were collected frequently for determination of cortisol. ... A clear reversal of circadian function could be observed for the total group (mean cortisol concentrations) after the fifth night. However, inspection of individual patterns revealed that six out of 24 subjects did not change in circadian function.”

Weibel and Brandenberger (1998) examined the adaptation of hormones “during the usual day sleep time (0700-1500 h) and during the usual night work time (2200-0600 h) in permanent night workers.” “During usual day sleep, despite an adapted sleep structure, cortisol levels among night workers were abnormally enhanced, whereas the TSH decreased in comparison to the plateau observed among day-active subjects. During usual work time, some hormonal disturbances persisted, in particular concerning cortisol and PRL (two hormones known to reflect the level of activation). Among night workers, the work time was associated with the quiescent period of cortisol secretion normally occurring during the first hours of sleep, and with a transient PRL increase.”

Weibel, Follénus, and Brandenberger (1999) reviewed their “repeated measurements every 10 min over a 24 hour period in night-shift workers to determine the precise melatonin, cortisol, and thyrotropin (TSH) patterns, which reflect the endogenous clock, and prolactin (PRL) and growth hormone (GH) patterns which are influenced by sleep but also have a circadian component.” They had “demonstrated that there is some, but partial, adaptation of the biological rhythms in these persons. The shift in the melatonin pattern is quite variable from one individual to another. Night work causes a distortion in the cortisol and TSH rhythms. This partial adaptation is also seen in the GH and PRL curves, mainly related to sleep, but whose endogenous component previously described in other experimental situations is found in night workers with a distribution incompletely adapted to the secretory episodes.”

Simon, Weibel, and Brandenberger (2000) examined the adaptation of “the ultradian and circadian rhythms of glucose and insulin secretion rate (ISR) to a permanent night work schedule.” “The duration and the number of the ultradian oscillations were influenced neither by the time of day nor by the sleep condition or its shift, but their mean amplitude increased during sleep whenever it occurred. In day-active subjects, glucose and ISR levels were high during nighttime sleep and then

decreased to a minimum in the afternoon. After the acute sleep shift, the glucose and ISR rhythms were split in a biphasic pattern with a slight increase during the night of deprivation and another during daytime sleep. In night workers, the glucose and ISR peak levels exhibited an 8-hour shift in accordance with the sleep shift, but the onset of the glucose rise underwent a shift of only 6 h and the sleep-related amplification of the glucose and ISR oscillations did not occur simultaneously. These results demonstrate that despite a predominant influence of sleep, the 24-hour glucose and ISR rhythms are only partially adapted in permanent night workers."

Karlsson, Knutsson, and Lindahl (2001) explored "how metabolic risk factors for cardiovascular disease differ between shift workers and day workers in a defined population." "Obesity was more prevalent among shift workers in all age strata of women, but only in two out of four age groups in men. Increased triglycerides (>1.7 mmol/l) were more common among two age groups of shift working women but not among men. Low concentrations of high density lipoprotein (HDL) cholesterol (men <0.9 and women <1.0 mmol/l) were present in the youngest age group of shift workers in both men and women. Impaired glucose tolerance was more often found among 60 year old women shift workers. Obesity and high triglycerides persisted as risk factors in shift working men and women after adjusting for age and socioeconomic factors, with an OR of 1.4 for obesity and 1.1 for high triglyceride concentrations. The relative risks for women working shifts versus days with one, two, and three metabolic variables were 1.06, 1.20, and 1.71, respectively. The corresponding relative risks for men were 0.99, 1.30, and 1.63, respectively."

Lund, Arendt, Hampton, English, and Morgan (2001) "investigated the responses to standard meals at different circadian times in a group of night-shift workers on a British Antarctic Survey station at Halley Bay (75 degrees S) in Antarctica." Their rationale was that "The circadian rhythms of many night-shift workers are maladapted to their imposed behavioural schedule, and this factor may be implicated in the increased occurrence of cardiovascular disease (CVD) reported in shift workers. One way in which CVD risk could be mediated is through inappropriate hormonal and metabolic responses to meals."

During normal daytime working, aMT6s acrophase was delayed compared with that previously found in temperate zones in a comparable age-group. During the night shift a further delay was evident and subjects' acrophases remained delayed 2 days after return to daytime working. Integrated postprandial glucose, insulin and TAG responses were significantly elevated during the night shift compared with normal daytime working. Two days after their return to daytime working, subjects' postprandial glucose and insulin responses had returned to pre-shift levels; however, integrated TAG levels remained significantly elevated. These results are very similar to those previously found in simulated night-shift conditions; it is the first time such changes have been reported in real shift workers in field conditions. They provide evidence that the abnormal metabolic responses to meals taken at night during unadapted night shifts are due, at least in part, to a relative insulin resistance, which could contribute to the documented cardiovascular morbidity associated with shift work."

Nagaya, Yoshida, Takahashi, and Kawai (2002) examined "relationships between shift work and markers (metabolic abnormalities) of insulin resistance (IR)" in a cross-sectional study of 2,824 day and 826 shift workers. "Hypertriglyceridemia was most prevalent, and hyperglycemia was least, in the four IR markers in both worker groups. Approximately half of the subjects had at least one IR marker in both groups. However, a full cluster of IR markers was rare in both groups (N=4; 0.2% and 0.1%, respectively). Prevalence of IR syndrome by any cutpoints increased with age in day workers, but shift

workers aged 50 years or older had lower prevalence than shift workers younger than 50 years. In subjects younger than 50 years, all IR markers (except for hypo-HDL-cholesterolemia) and IR syndrome by any cutpoints were more prevalent in shift workers than in day workers. Contrariwise, in subjects aged 50 years or older, lower prevalence of all IR markers and IR syndrome in shift workers than in day workers was found. ... Shift work may be associated with IR syndrome in workers younger than 50 years."

Karlsson, Knutsson, Lindahl, and Alfredsson (2003) investigated "the relationship between important metabolic risk factors for coronary heart disease (CHD) and type 2 diabetes in shift workers and day workers" using cross-sectional data from a sub-population in the WOLF study consisting of 665 day workers and 659 three-shift workers in two plants." "A higher proportion of shift workers than day workers had high triglyceride levels, low levels of HDL-cholesterol and abdominal obesity. The risk of low HDL-cholesterol was doubled in shift workers after being adjusted for age, socio-economic factors, physical activity, current smoking, social support and job strain. High levels of triglycerides were also significantly associated with shift work. The OR for abdominal obesity was 1.19. The prevalence of hyperglycaemia was similar in day and shift workers. No significant interaction was seen between shift work and abdominal obesity with regard to the associations with triglycerides and HDL-cholesterol."

Morgan, Hampton, Gibbs, and Arendt (2003) reviewed the "time-dependent differences in postprandial responses [that] have implications for shiftworkers." They noted that "Night shift workers are reported to have an approximately 1.5 times higher incidence of heart disease risk and also demonstrate higher TAG levels compared with matched dayworkers. As both insulin resistance and elevated circulating TAG are independent risk factors for heart disease, it is possible that meals at night may contribute to this risk."

Di Lorenzo et al. (2003) examined "the influence of shift work on metabolic and cardiovascular risk factors in subjects working in an industry sited in Apulia, Southern Italy." They conducted a "Cross-sectional study of metabolic effects of shift work in glucose tolerant workers." "The prevalence of obesity was higher among shift workers compared to day workers, whereas body fat distribution was not different between the two groups. Shift workers had higher BMI than day workers, and shift working was associated with BMI, independently of age and work duration. Shift workers had significantly higher SBP levels, which were independently influenced by BMI, but not by shift work, thus suggesting that the difference in SBP may well be mediated by the increased body fatness."

Al-Naimi, Hampton, Richard, Tzung, and Morgan (2004) compared "the cumulative metabolic effect of consecutive snacks/meals, as might normally be consumed throughout a period of night or day shift work" with respect to postprandial metabolic risk factors for cardiovascular disease among shift workers. They executed a randomized crossover study of eight healthy non-obese men. There was "a significant effect of shift for plasma [triacylglycerol], with higher levels on simulated night compared to day shift. There was a trend toward an effect of shift for plasma glucose, with higher plasma glucose at night, and there was a time-shift interaction for plasma insulin levels. [Non-esterified fatty acid] levels were unaffected by shift. Inspection of the area under the plasma response curve following each meal and snack revealed that the differences in lipid tolerance occurred throughout the study, with greatest differences occurring following the mid-shift snack. In contrast, glucose tolerance was relatively impaired following the first night-time meal, with no differences observed following the second meal. Plasma insulin levels were significantly lower following the first meal, but significantly higher following the second meal on the simulated night shift."

Park, Ha, Yunjeong, and Kim (2006) examined associations between urinary catecholamines and cortisol and subjective complaints of fatigue in shiftworkers in 113 male shiftworkers at a manufacturing company in South Korea. “[A]mong workers with less than 5 yr of shiftwork experience, the concentrations of norepinephrine, epinephrine (Epi), and dopamine during the afternoon shift were positively correlated with Set II (difficulties in concentration) and Set III (projection of disintegration) [with] subjective fatigue symptoms. In addition, Epi concentrations were positively correlated with Set I (drowsiness and dullness), II, and III of subjective fatigue symptoms during the night shift. However, among workers with 5 or more years of shiftwork experience, there was no significant positive correlation between urinary catecholamine and subjective fatigue symptoms. In the long term shiftwork experience group, only the complaints scores of Set II fatigue symptoms (difficulties in concentration) during the morning shift were significantly higher than those of the short-term shiftwork experience group within the same shift.”

De Valck et al. (2007) examined “simulator driving and subjective sleepiness after morning, afternoon, and night shifts and to compare these differences, as well as objective stress [salivary cortisol], between a fast-forward and a slow-backward rotating shift system.” “Salivary cortisol samples taken at the start of the workweek did not significantly differ between the fast-forward and the slow-backward rotation shift systems.”

Morikawa et al. (2007) investigated “the effects of shift work on changes in parameters related to metabolic disturbances” in 1,529 male workers. The age-adjusted mean increase in BMI was 1.03 kg/m² for day-to-shift workers, and it was significantly larger than that of continuing day workers and shift-to-day workers. Continuing shift workers showed a significantly larger increase in BMI than continuing day workers. ... The increase in total cholesterol tended to be higher among the continuing shift workers and the day-to-shift workers, but there were no significant differences. Blood pressure and hemoglobin A1c did not differ among the four groups.

Ketchum and Morton (2007) “investigated the effects of shift work on postoperative weight loss in bariatric surgery patients” in a “retrospective chart review of 389 patients” that included 8 shift workers. “Average postoperative excess weight loss for the shift workers was significantly lower than in the non-shift-workers at 6 months and at 12 months.”

Atkinson, Fullick, Grindey, and Maclaren (2008) reviewed “the behavioural and biological disturbances that occur during shift work and discuss their impact on leisure-time physical activity and energy balance” with respect to increased body mass index, prevalence of obesity and other health problems associated with shift work. They presented “a model of the various behavioural and biological factors relevant to exercise and energy balance during shift work as a framework for future research.”

Vangelova (2008a, 2008b, 2008c) studied the effects of “job task and fast backward-rotating shifts on the time-of-day variations of cortisol, fatigue, and sleep disturbances in broadcasting sound engineers.” “Cortisol retained the typical diurnal pattern with a highly significant effect of the shift. The job task and the shift interacted significantly. Higher cortisol values during the morning and night shifts in engineers working in direct transmissions were found.”

Griefahn and Robens (2008) examined “the possible influence of experimental shift work, morningness and sleep length on the cortisol awakening response (CAR)” in eight morning-oriented (MT) and eight evening-oriented (ET) healthy young men. “The CAR was significantly smaller after day

than after night sleep and increased significantly with total sleep time in ET. MT had moderately higher cortisol concentrations upon awakening than ET probably because they wake up at a later time of their circadian rhythm. But neither the CARs nor the cortisol concentrations during the following work shifts or during the 24h profiles were different in both diurnal types. The cortisol concentrations during work shifts correlated significantly with the previous post-awakening concentrations in MT but not in ET."

Copertaro, Bracci, Barbaresi, and Santarelli (2008b) compared "the criteria of the National Cholesterol Education Panel (NCEP), revised NCEP (NCEP-R) and International Diabetes Federation (IDF) metabolic syndrome [MS] criteria for the diagnosis of MS, also to explore how metabolic risk factors for CVD [cardiovascular disease] differ between shift workers and day workers in a cohort of [552] Italian workers." "In comparison with day workers, rotating shift nurses had greater waist circumference, higher serum triglycerides and fasting plasma glucose, and lower concentrations of HDL cholesterol ... No significant association between MS and shift work was found. ... Shift work was significantly associated with high triglycerides and abdominal obesity using IDF criteria. Measurement of waist circumference is a simple and non-invasive method to use in the evaluation of metabolic risk factor for CVD."

Violanti et al.(2009) "examined whether atypical work hours are associated with metabolic syndrome among a random sample of 98 police officers." "Officers working midnight shifts were on average younger and had a slightly higher mean number of metabolic syndrome components. Stratification on sleep duration and overtime revealed significant associations between midnight shifts and the mean number of metabolic syndrome components among officers with less sleep and more overtime. Results suggest shorter sleep duration and more overtime combined with midnight shift work may be important contributors to the metabolic syndrome."

Suwazono et al. (2009) assessed "the effect of shiftwork on hemoglobin A1c (HbA1c) level, as an index of glucose metabolism." "A 14 yr prospective cohort study was conducted on day (n = 4219) and alternating shiftworkers (n = 2885) who received annual health checkups between 1991 and 2005 at a Japanese steel company. ... Shiftwork was significantly associated with the various HbA1c endpoints. Age, body mass index, alanine aminotransferase, and gamma-glutamyl transpeptidase were associated positively with all five HbA1c endpoints. Uric acid was associated negatively with all five HbA1c endpoints. Our study on male Japanese workers revealed alternating shiftwork (in addition to other established factors, such as age and body mass index) was a consistent risk factor for impaired glucose metabolism."

Korompeli, Sourtzi, Tzavara, and Velonakis (2009) investigated whether "an irregular rotating shift system, including night shifts, can cause changes to the secretion of hormones in nurses." "The mean reduction of cortisol level between the two measurements was statistically significantly greater for the 'rotating' than 'morning' shift group. There were no statistically significant differences between the two groups in overall mean change from the first to the second measurement of prolactin, triiodothyronine and thyroid-stimulating hormone. Levels of thyroxine increased statistically significantly in the 'rotating' group but not in the 'morning' group. The morningness scale score was greater for the 'rotating' group, while greater job satisfaction levels were found in the 'morning' group. Statistically significant correlations were found between thyroid-stimulating hormone, triiodothyronine, thyroxine and prolactin changes and specific scales of the SSI questionnaire."

6. Reproductive Health

Nurminen (1989) analyzed “Information on 1475 mothers of infants with selected structural malformations and an equal number of mothers of ‘normal’ babies,” seeking a possible relationship between shift work and adverse pregnancy outcome or a complicated course of pregnancy. “No signs of a teratogenic risk were observed. The relationship between course of pregnancy and outcomes other than malformations was determined from the non-case mothers’ experience. Threatened abortion and pregnancy-induced hypertension were not associated with rotating shift work alone, but in a noisy work environment moderate risks could not be ruled out. Rotating shift work was associated with a slight excess of babies small for their gestational age independently of noise exposure.” Nurminen (1995) found “that occupational noise at the level of approximately 85 dB LAeq(8 h) or higher and shift work, especially rotating schedules, may have independent negative effects on birth weight and length of gestation.” Female noise exposure should be avoided. In a subsequent review, Nurminen noted that “Two newly published studies suggest an association between rotating shift work and prolonged waiting time to pregnancy. Seven of nine studies on spontaneous abortion suggest that some forms of shift work may be associated with increased risk. Four studies indicate that shift work including night schedules may be related to preterm birth. Moreover, some results have related rotating schedules to intrauterine growth retardation” (Nurminen, 1998).

Xu, Ding, Li, and Christiani (1994) surveyed “1035 married women workers in three modern textile mills in Anhui, China” to “investigate the association of rotating shiftwork with low birth weight and preterm birth in 1992.” “Multiple linear regression was used to adjust for confounding factors including maternal age at pregnancy, order of live birth, mill location, job title, occupational exposure to dust/gases/fumes, stress, carrying and lifting of heavy loads, working in a squat position, time and duration of leave from the job since pregnancy, and indoor coal combustion for heating. The adjusted difference in gestational age associated with rotating shifts was statistically significant. Mean birth weights were 3248 g and 3338 g for rotating shift workers and regular schedule workers, respectively. The estimated effect of rotating shiftwork on birth weight was -79 (SE 42) g. When the analysis was restricted to first order live births or to production workers, the estimated effects of rotating shiftwork on both gestational age and birth weight were significant. The proportions of preterm birth (<37 weeks) and low birth weight (<2500 g), respectively, were 20% and 9% for shift workers and 15% and 6% for regular schedule workers. The adjusted odds ratio of shiftwork was 2.0 for preterm birth and 2.1 for low birth weight. This association remained significant when the analysis was restricted to production workers or first order live births.”

Bisanti, Olsen, Basso, Thonneau, and Karmaus (1996) measured the Time of Unprotected Intercourses (TUI) in couples recruited in the European Studies on Infertility and Subfecundity to analyze the effect of shift work on fecundity. “A low (odds ratio < 2.0) but consistent excess risk of subfecundity (TUI > or = 9.4 months) has been observed both in a representative sample of the general population of women in reproductive age and in a sample of pregnant women or women who had just given birth. The excess risk was also consistently evident both in the subsample of the first pregnancies and in the subsample of the most recent pregnancies. Only the exposure of women to shift work seemed to affect a couple’s fecundity; men working shift work did not modify the fecundity pattern of their own couples.”

Tuntiseranee, Olsen, Geater, and Kor-anantakul (1998) estimated “the effect of long working hours and shift work on time to pregnancy” among 1496 pregnant women attending pre-natal

clinics in Thailand. Analyses “showed an odds ratio (OR) associated with female exposure to long working hours of 2.3 in primigravid and 1.6 in all pregnant women. Male exposure to long working hours and shiftwork showed no association with subfecundity. The OR of subfecundity was highest when both partners worked > 70 hours a week irrespective of the cut off point used.”

Zhu, Hjollund, Boggild, and Olsen (2003) used the Danish National Birth Cohort (DNBC) to examine whether shift work is associated with reduced fecundity as estimated by time to pregnancy (TTP). “Fixed evening workers and fixed night workers had a longer TTP. Compared with daytime workers, the adjusted ORs were 0.80 for fixed evening workers, 0.80 for fixed night workers, 0.99 for rotating shift (without night) workers, and 1.05 for rotating shift (with night) workers. When analysis was restricted to nulliparous women, the estimates remained unchanged. The proportions of unplanned pregnancies and contraceptive failures were higher among fixed evening and fixed night workers.” Zhu, Hjollund, and Olsen (2004) also estimated the effect of shift work on the duration of pregnancy and birth weight. “Mean gestational age at birth and birth weight at term for daytime work were 281 days and 3616 g, although 281 days and 3586 to 3626 g for shift work. There were no statistically significant differences in gestational age at birth or birth weight at term between any types of shift work and daytime work. Fixed night work had a high risk of post-term birth (odds ratio, 1.35); fixed evening work had a high risk of full-term low birth weight (odds ratio, 1.80); and shift work as a group showed a slight excess of small-for-gestational-age babies (odds ratio, 1.09). The risk of post-term birth was modified by maternal occupation. Industrial workers with fixed night work had a high risk of post-term birth.”

Schernhammer et al. (2004) “examined the reproducibility of morning urinary measurements of 6-sulfatoxymelatonin over a 3-year period in 80 premenopausal women.” “We found significantly increased levels of estradiol after longer durations of night work. We observed a significant inverse association between increasing number of nights worked within the 2 weeks preceding urine collection and urinary melatonin levels, but no association of recent night work with estradiol. ... Women who work on rotating night shifts seem to experience changes in hormone levels that may be associated with the increased cancer risk observed among night-shift workers.”

Schlünssen, Viskum, Omland, and Bonde (2007) reviewed “22 epidemiological papers were studied looking at associations between shift work and abortion, stillbirth, preterm birth, and birth weight.” “No convincing associations were observed between rotating shift work or fixed nightshift and negative pregnancy outcome. Some epidemiological support was found for a relation between fixed nightshift and late abortions/stillbirth.”

Bonzini, Coggon, and Palmer (2007) assessed “the evidence relating three major adverse outcomes (preterm delivery, low birthweight (LBW) and pre-eclampsia/gestational hypertension) to five common occupational exposures (prolonged working hours, shift work, lifting, standing and heavy physical workload).” “For pre-term delivery, extensive evidence relating to each of the exposures of interest was found. Findings were generally consistent and tended to rule out a more than moderate effect size (RR >1.4). ... For small-for-gestational age, the position was similar, but the evidence base was more limited. For pre-eclampsia and gestational hypertension, it was too small to allow firm conclusions.”

7. Sleep

Anderson, Chambers, Myhre, Nicholson, and Stone (1984) investigated the sleep of shiftworkers in the Arctic with electroencephalography four times a year over a 2-year period. "There was a trend toward less restful sleep during the autumn and winter months, but otherwise sleep at various times of the day was similar to that of individuals elsewhere."

Torsvall, Akerstedt, Gillander, and Knutsson (1989) described "the spontaneous sleep/wakefulness pattern of shift workers during a 24-hour period" through ambulatory EEG monitoring of 25 male papermill workers. "The results showed that sleep after night work was two hours shorter than after afternoon work. The sleep reduction affected mainly Stage 2 and REM sleep while slow wave sleep was unchanged. In connection with night work 28% of the workers took a nap in the afternoon. These naps contained a large proportion of slow wave sleep and were, apparently, caused by the sleep deficit after the short main sleep period. The EEG recordings also revealed that 20% of the participants had sleep episodes during night work. These naps were as long as the afternoon naps, were experienced as 'dozing offs' rather than naps, occurred at the time of the trough of the circadian wakefulness rhythm, and were concomitant with extreme subjective sleepiness and low rated work load."

Naitoh, Kelly, and Englund (1990) provided "information supporting the conclusion that sleep deprivation produces only very small biomedical effects." "It nonetheless concludes that chronic partial sleep deprivation may contribute to gastrointestinal disorders, cardiovascular disease, and other medical conditions that occur more often in shiftworkers than in permanent dayworkers."

Tepas and Carvalhais (1990) provided an assessment of shiftworkers' sleep behaviors and implications thereof, as follows. "Work hours affect sleep because the sleep behavior of shiftworkers on non-workdays differs from that on workdays. For most shiftworkers, workday sleep is shorter than non-workday sleep. On non-workdays most shiftworkers sleep at night. On workdays, people on the nightshift sleep the least, people on the afternoon/evening shift sleep the most, and people on the dayshift sleep less than those on the afternoon/evening shift but more than those on the nightshift. Thus, the infradian sleep strategy elected by a shiftworker across several days is ordinarily related to the schedule worked. Despite historical preconceptions that nightshift work disturbs sleep, the primary problem appears to be a workday reduction in sleep length, for which most shiftworkers do not usually compensate by getting more sleep on their non-workdays. Polysomnographic studies of workers on the nightshift show ultradian sleep-stage sequencing similar to that of people who have chronically reduced their usual sleep duration. This chronic reduction in sleep length is evident in data from experienced nightshift workers, including those who most prefer to work nights. Experienced night shiftworkers also manifest decrements in performance of the sort expected of people suffering from chronic sleep deprivation. It seems reasonable to suggest that chronic sleep deprivation of night shiftworkers may often be a productivity, safety, or health hazard. Sleep disorders may be a secondary problem also facing nightshift workers. In general, shiftworkers who do night shiftwork report difficulty falling asleep or staying asleep at rates higher than workers who do not work nights. Data suggest that this may be due to the regular practice of inappropriate infradian sleep strategies or to chronic napping habits. At this point in our study of shiftworker sleep behavior, there is as yet no clear evidence that nightshift workers suffer from clinical sleep disorders at a higher rate than other workers. It is reasonable to suggest that occupational health professionals can make initial assessments of the sleep complaints made by night shiftworkers. Subjective measurements can be

used for these assessments if care is taken to use appropriate methods. It is recommended that this data be collected by asking workers quite literal and concrete questions about the time of day they usually elect to go to sleep and get up. A sleep survey of this sort should gather main sleep period and napping times for both workdays and nonworkdays, so that the infradian sleep strategy of the worker can be identified.”

Åkerstedt, Kecklund, and Knutsson (1991a) subjected 14 male rotating 3-shift workers to 24-hour ambulatory polysomnographic recording in connection with morning, afternoon, and night shift work at home and at work. “Total sleep time, stage 2, rapid-eye-movement sleep, and slow-wave sleep (stages 3 + 4) were significantly reduced during sleep in connection with the night and morning shifts. Other visually scored sleep parameters and slow-wave energy (spectral power density integrated across sleep) were not affected. The content of the sleep cycles did not differ between shifts. The sleep before the morning shift was characterized by subjectively increased difficulties of sleep initiation and sleep termination, as well as by insufficient recuperation. The night shift was characterized by increased subjective difficulties of maintaining sleep, but also by increased ease of sleep initiation.” Åkerstedt, Kecklund, and Knutsson (1991b) also subjected 25 3-shift workers in a process industry to ambulatory polysomnography during one afternoon and one night shift.

“Subjective sleepiness increased during the night work but did not reach an extreme level. Five subjects fell asleep during night work and the involuntary naps were preceded by a few minutes of increased alpha

(8-11.9 Hz) power density. Alpha and theta activity occurred in very short bursts. The hourly mean EEG alpha power density increased significantly but moderately during the night shift and correlated with subjective ratings of sleepiness. Theta power density

(4-7.9 Hz) did not increase during the night shift, nor did it correlate with subjective sleepiness. It was suggested that the shift workers could prevent much of the polysomnographic manifestations of sleepiness by various types of activity (including succumbing to sleep). It was also suggested that averaging power density values across long time periods might not be an optimal strategy for detection of sleepiness, but rather some method of emphasizing the occurrence of alpha or theta bursts.”

Åkerstedt and Kecklund (1991) subjected 20 rotating 3-shift workers to 24-hour ambulatory polysomnographic recording techniques, and repeated the procedure two years later. “Both day and night sleep showed high significant correlations between years for rapid eye movement (REM) sleep, slow wave sleep (SWS-stages 3 + 4), total sleep time, slow wave energy, in the delta band (obtained via spectral analysis) and subjective sleep quality. Stage 2, stage 1, percent waking, sleep latency, SWS latency and REM latency were not correlated across years. None of the variables showed a significant difference between years. It was concluded that core variables of sleep show considerable inter-individual stability across time and that a 2-year exposure to rotating shift work does not affect sleep in experienced shift workers.”

Kieswetter (1993) compared “the effects of morning and afternoon sleep behaviour on sleep quality within and after a period of seven night shifts.” “Morning and afternoon sleepers showed some differences in the trend of sleep changes over successive sleep periods. However, at the end of the night shift week, there were no marked differences in sleep quality. Both morning and afternoon sleep were characterized by deep sleep, and short sleep onset latencies.”

Siebenaler and McGovern (1991) provided a review in which they concluded that “The most direct and consistent effect of working shiftwork is the impairment of the quality and quantity of sleep.” Åkerstedt (1995) noted that “shift work is associated with severe sleepiness on the night shift and to some extent on the morning shift. This sleepiness is at least as severe as that seen in hypersomnia and is associated with a strongly increased risk of accidents. The reason for night shift sleepiness is work at the circadian nadir, extended periods of wakefulness, and truncated sleep. Much of the sleepiness in shift work may be predicted using a quantitative model.”

Matsumoto et al. (1996) performed studies “to clarify (1) the actual conditions concerning rotating shift schedules of nurses in Japanese university and college hospitals and to evaluate (2) some aspects of the physical and mental health, and (3) sleep profile of hospital nurses working on counter-clockwise shift rotation.” “The results of study (3) were as follows: 1) In five of [the] sleep factors (Sleepiness, Integrated sleep, sleep initiation) and GS [the global score of subjective sleepiness], there were significant differences among each rotating shift schedule including day off; 2) The highest score in five of [the] sleep factors and the highest GS were noted after the 2nd night shift (nocturnal sleep), and the lowest after the 1st night shift (diurnal sleep).”

Stone and Turner (1997b) described “A number of techniques and treatments [that] can be used to alleviate the sleep disturbance associated with both shiftwork and transmeridian travel.” “Optimization of the sleeping environment and avoidance of substances such as caffeine and alcohol before sleep are the best initial approach. Timing sleep to coincide with some of the normal sleep period where possible will improve sleep quality in shiftworkers. ... Hypnotic drugs may be of benefit to alleviate sleep disturbance experienced by shiftworkers or transmeridian travelers. Selection of the most appropriate medication must take into account required duration of action and possible residual effects of the drug on alertness. Hypnotics may be useful, particularly in middle-aged individuals who already have disturbed sleep, on those occasions when poor sleep is anticipated, for example following an eastward flight or after the initial change to night duty. Over-the-counter preparations should be avoided whenever possible unless it is known that they are not associated with residual sequelae.”

Gillberg (1998) used sleep diaries to “compare permanent 12-hour day and night shifts (shift change over times at 0500 and 1700) in a shift system with 3 work periods followed by 4 free days.” “The day workers were significantly sleepier during their workdays. Times for going to bed and for rising differed between the groups. The amount of sleep per week did not differ between groups, but the pattern across days did in that the day workers had a short sleep (5 hours) before the first day and 6 hours of sleep after the other two. Night workers slept long (9 hours) before the first shift and had 6.5-hour sleep periods after the other shifts. During free time the day workers slept around 9 hours and the night workers around 8 hours. Sleep quality and ease of awakening showed no group differences in overall levels, but the day workers had difficulties awakening before their shifts. The night workers had little variation in sleep quality or difficulties awakening.”

Härmä, Tenkanen, Sjöblom, Alikoski, and Heinsalmi (1998) studied “The combined effects of age, leisure-time physical activity, smoking, alcohol consumption, and different forms of shift work on the prevalence of sleep complaints and daytime sleepiness” among 3,020 workers in industry, transport, and traffic with a questionnaire. “The prevalence of insomnia, sleep deprivation, and daytime sleepiness depended significantly on the shift system. All sleep complaints were more common in 2- and 3-shift work and in irregular shift work than in day work. The prevalence of daytime sleepiness was 20-37%, depending on the shift system. Leisure-time physical activity and alcohol

consumption were the most important life-style factors predicting all sleep complaints, except snoring. The effects of physical activity and alcohol consumption differed for different shift schedules. ... Different shift systems, also 2-shift work and permanent night work, seem to increase the frequency of sleep complaints. Especially 3-shift work seems to interact with life-style factors by increasing the adverse effects and decreasing the beneficial effects on sleep and sleepiness."

Garbarino et al. (2001) noted that "there is a decrease in the number of hours of sleep both during morning shifts, due to early awakening, and during night shifts due to the inversion of the normal sleep-wake cycle." Stone (2000) noted that "The changes in performance that arise in shiftworkers can be attributed, at least in part, to the reduction in both the quality and quantity of sleep which occurs as a result of disruption of the normal pattern of sleep and wakefulness. Sleep disturbance associated with shiftwork is well documented."

Delafosse, Léger, Quera-Salva, Samson, and Adrien (2000) validated "actigraphy in comparison with polysomnography for sleep evaluation and to assess nurses' adaptation to sleep/wake cycles when on a permanent night shift schedule." "Actigraphy and ambulatory polysomnography were performed in fifteen night shift nurses employed in hospital on a full time basis, during their work and their rest periods. Our first findings showed that actigraphy gave reliable results compared with polysomnography in evaluation of total sleep time. In addition, it was found that seven of the nurses exhibited, during their work periods, an approximately five-hour delay in the acrophase of their rest/activity rhythm compared with their rest periods. In contrast, five other nurses whose acrophase did not change between work and rest periods, exhibited sleep episodes of more than 100 minutes duration at work. These results confirm data in the literature and show that some nurses cannot adjust the circadian rhythm of their inner biological clock to their nocturnal schedules. Actigraphy seems to be an efficient, low cost and easy method for measuring total sleep time as well as for assessing the inability of nurses to adapt to permanent night shift work."

Garbarino et al. (2001) evaluated the effects of shiftwork on sleepiness, sleep disorders and sleep related accidents in a population of 1,280 policemen by questionnaire, of whom about half were shiftworkers. "The ESS scores were not higher in shiftworkers than in non-shiftworkers, but the [sleep disorders] score was found to be significantly influenced by shiftwork condition and seniority. The occurrence of sleep-related accidents was found to have been significantly increased for shiftworkers and related to the presence of indicators of sleep disorders." Garbarino, De Carli, et al. (2002) also found that the Epworth Sleepiness Score was not higher in shiftworkers than in non-shiftworkers, while the sleep disorders score was significantly influenced by shift-work conditions and seniority in shift work.

Kwarecki and Zuzewicz (2002) investigated the circadian rhythms of locomotor activity and sleep in air traffic controllers (ATCs) at the Okecie Airport of Warsaw using actigraphy. "Sleep disturbances, most often sleep latency, shortening of the main sleep and more frequent naps increase with age and work experience."

Garbarino et al. (2002b) "investigated sleep habits, prevalence of sleep disorders, sleepiness on the job, and hypnotic drug intake" with questionnaires in a population of 1,115 Italian state police officers," about half of whom were shiftworkers. "In shiftworkers, there was a higher prevalence of difficulty in initiating sleep; in addition, these individuals had a sleep latency that exceeded 20 min, and they experienced early awakenings. No significant differences in daytime sleepiness and drug intake existed between the 2 groups. Self-evaluation of the number of hours that individuals slept each night

and during a 24-hr period revealed that shiftworkers required more sleep. The results indicated that shiftworkers experienced a lower quality of sleep than non-shiftworkers, but the former did not report increased daytime sleepiness or increased hypnotic drug intake (i.e., Benzodiazepines, Zaleplon, Zolpidem, or Zopiclone). Shiftworkers seemed to compensate for the poor quality of their sleep by sleeping for a greater number of hours during 24-hr periods than the non-shiftworkers.”

Ohayon, Lemoine, Arnaud-Briant, and Dreyfus (2002) used the Sleep-EVAL system to interview 817 staff members of a psychiatric hospital. “Subjects working on rotating daytime shifts were younger than the two other groups and had a higher proportion of women. Participants working on rotating daytime shifts reported more frequently than the fixed daytime schedule workers to have difficulty initiating sleep (20.1% vs. 12.0%). The sleep duration of shift or nighttime workers was shorter than that of the two other groups. Furthermore, subjects working rotating daytime schedule reported to have shorter sleep duration of about 20 min when they are assigned to the morning shift.”

Portela, Rotenberg, and Waissmann (2004) “tested the hypothesis that the prevalence of diseases, sleep complaints, and insufficient time for nonprofessional activities (family, leisure, and rest) are higher among night than day workers” using questionnaires with 258 nurses in Brazil, almost all of whom worked shifts of 12+ hours. “Reports of migraine and need of medical care the 2 weeks before the survey were more prevalent among day than night workers. Migraine headaches occurred less frequently among night than day workers as confirmed by comparing the reports of the night workers and day workers whose work history was always day shifts. Reports of mild emotional disorders (mild depression, tension, anxiety, or insomnia) were less frequent among night and ex-night workers than day workers who never had worked a night job. ... The possible role of exposure by day workers to some risk factors, such as stress, was suggested as an explanation for these results. No significant difference was observed between night and day workers as to sleep complaints, a result that may have been influenced by the nature of the shift-work schedule (no successive night shifts) and possibly nap taking during the night shift. ... Among night workers, a significant relation was found between years working nights (more than 10 yrs) and high cholesterol values.... Working nights more than four times per 2-week span was related to complaints about insufficient time for children and rest/leisure.”

Folkard, Lombardi, and Tucker (2005) reviewed “the available published literature on shiftwork and safety that allows the relative risk of ‘accidents’ or injuries associated with specific features of shift systems to be estimated.” “Three main trends in risk are discussed, namely that (i) risk is higher on the night shift, and to a lesser extent the afternoon shift, than on the morning shift, (ii) risk increases over a span of shifts, especially so if they are night shifts, and (iii) risk increases with increasing shift length over eight hours. We discuss that some of these trends are not entirely consistent with predictions derived from considerations of the circadian variations in sleep propensity or rated sleepiness, and consider factors relating to sleep that may underlie the observed trends in risk. Finally, the practical implications of the trends in risk for the design of safer shift systems are discussed.”

Sallinen et al. (2005) “examined the occurrence of sleepiness in various shift combinations ending with a night or morning shift.” See the Occupational Safety and Risk section, above. Sveinsdóttir (2006) compared “the self-assessed quality of sleep, occupational health, working environment, illness experience and job satisfaction among [348] female nurses working different combinations of shifts” in Iceland. “No difference was found between participants based on type of shift with regard to ... quality of sleep.” Choobineh, Rajaeefard, and Neghab (2006) carried out a cross-sectional study of shiftwork-related problems among health care workers at hospitals of Shiraz

University of Medical Sciences, Islamic Republic of Iran. "Sleep ... problems were more prevalent in shiftworkers than day workers."

Fido and Ghali (2008) explored "the detrimental effects of working a varying pattern of 8-hour shifts on quality of sleep, general health and work performance" in 200 male workers at the Kuwait Oil Company. "Variable-shift workers reported persistent sleep disturbances in 3 dimensions of the global score of the PSQI ($p < 0.0001$). They also had significantly more complaints of fatigue ($p < 0.005$), poor level of work performance ($p < 0.005$) and loss of concentration ($p < 0.005$). Shift workers were significantly more prone to making errors and having accidents at work."

Åkerstedt and Wright (2009) noted that night work has "pronounced negative effects on sleep, subjective and physiologic sleepiness, performance, accident risk, and health outcomes such as cardiovascular disease and certain forms of cancer." "Although some countermeasures may be used to ameliorate the negative impact of shift work on nighttime sleepiness and daytime insomnia (combined countermeasures may be the best available), there seems to be no way to eliminate most of the negative effects of shift work on human physiology and cognition."

a. Shift Work Sleep Disorder

The *International Classification of Sleep Disorders* (ICSD) is published by the American Academy of Sleep Medicine (2001). The ICSD may be downloaded from several Websites. Shift Work Sleep Disorder (SWSD) is coded in the ICSD as 307.45-1, a circadian sleep disorder, and was included in the initial edition of the ICSD in 1990. Synonyms and key words include: night shift, irregular work hours, transient insomnia, transient excessive sleepiness, "work-shift" change in conventional sleep-wake schedule, acute-phase shift of sleep, and frequently changing sleep-wake schedule. The essential features of SWSD are:

Shift work sleep disorder consists of symptoms of insomnia or excessive sleepiness that occur as transient phenomena in relation to work schedules.

The work is usually scheduled during the habitual hours of sleep (i.e., shift work—rotating or permanent shifts), roster work, or irregular work hours. The sleep complaint typically consists of an inability to maintain a normal sleep duration when the major sleep episode is begun in the morning (6 a.m. to 8 a.m.) after a night shift. The reduction in sleep length usually amounts to one to four hours (mainly affecting REM and stage 2 sleep). Subjectively, the sleep period is perceived as unsatisfactory and unrefreshing. The insomnia appears despite the patient's attempts to optimize environmental conditions for sleep. The condition usually persists for the duration of the work-shift period. Early morning work shifts (starting between 4 a.m. and 7 a.m.) may also be associated with complaints of difficulty in sleep initiation as well as difficulty in awakening. Work on permanent evening shifts can be associated with difficulties initiating the major sleep episode. Excessive sleepiness usually occurs during shifts (mainly night) and is associated with the need to nap and impaired mental ability because of the reduced alertness (American Academy of Sleep Medicine, 2001, p. 122).

Regestein and Monk (1991) reviewed subjective responses to recent survey questions about sleep and polysomnographic measurements of sleep in shift workers and described sleep clinic experiences with complaints related to shift work. Their objective was to describe the impact of shift work on sleep, as recently acknowledged in official nosologies of sleep disorders, and to discuss whether sleep altered by shift work actually constitutes a disorder. "Shift work entails wide variation in work schedules, sleep quality, and worker tolerance and a high prevalence of night-shift sleepiness. It probably affects rates of drug use, health status, and family organization. Clinical presentations were rare, highly varied, and empirically treated. The

United States, unlike other countries, has no legal restrictions on shift work. As a clinical phenomenon, sleep altered by shift work is common and varied, probably expresses non-physiological sleep-wake scheduling, and is little treated. Further study of its health effects and consideration of whether it is a 'disorder' or a 'problem' seem warranted."

Richardson and Malin (1996) noted that "formal classification of sleep pathology has expanded ... to include six specific disorders." "Each of the circadian sleep disorders-time zone change (jet lag) syndrome, shift work sleep disorder, irregular sleep/wake pattern, delayed sleep phase syndrome, advanced sleep phase syndrome, and non-24-hour sleep wake disorder-is reviewed."

Drake, Roehrs, Richardson, Walsh, and Roth (2004) examined "the relative prevalence and negative consequences associated with shift work sleep disorder in a representative sample [n = 2,570] drawn from the working population of metropolitan Detroit." "Using standardized techniques, individuals were assessed for the presence of insomnia and excessive sleepiness, based on DSM-IV and ICSD criteria. Those individuals with either insomnia or excessive sleepiness and who were currently working rotating or night schedules were classified as having shift work sleep disorder. Occupational, behavioral, and health-related outcomes were also measured. Individuals who met criteria for shift work sleep disorder had significantly higher rates of ulcers, sleepiness-related accidents, absenteeism, depression, and missed family and social activities more frequently compared to those shift workers who did not meet criteria. Importantly, in most cases, the morbidity associated with shift work sleep disorder was significantly greater than that experienced by day workers with identical symptoms." The investigators suggested that "the prevalence of shift work sleep disorder is approximately 10% of the night and rotating shift work population."

Schwartz and Roth (2006) noted that "The negative consequences of shift work have been established, and recent evidence suggests that patients with shift work sleep disorder (SWSD) are at increased risk of these consequences and co-morbidities." Also, that "To date, three randomised, double-blind clinical studies have evaluated pharmacological therapies in patients with SWSD. These studies showed that modafinil and armodafinil significantly improve the ability to sustain wakefulness during waking activities (e.g. working, driving), overall clinical condition, and sustained attention or memory in patients with SWSD." "SWSD is a common condition that remains under-recognised and under-treated."

Sack et al. (2007a, 2007b) provided a two-article review of "the scientific literature on the evaluation and treatment of circadian rhythm sleep disorders (CRSDs), employing the methodology of evidence-based medicine." In the first part of article, "the general principles of circadian biology that underlie clinical evaluation and treatment are reviewed. We then report on the accumulated evidence regarding the evaluation and treatment of shift work disorder (SWD) and jet lag disorder (JLD)." In the second article, they "report on the accumulated evidence regarding the evaluation and

treatment of Advanced Sleep Phase Disorder (ASPD), Delayed Sleep Phase Disorder (DSPD), Free-Running Disorder (FRD) and Irregular Sleep-Wake Rhythm (ISWR).” They conclude that “Circadian rhythm science has also pointed the way to rational interventions for CRSDs and these treatments have been introduced into the practice of sleep medicine with varying degrees of success. More translational research is needed using subjects who meet current diagnostic criteria.”

The National Sleep Foundation provides several pamphlets concerning sleep for shiftworkers at www.sleepfoundation.org.

b. Sleep Apnea

Klawe, Laudenska, Miśkowiec, and Tafil-Klawe (2005; Tafil-Klawe, Laudenska, Klawe, & Miśkowiec, 2005) focused “on the occurrence of breathing disturbances during sleep in shift workers.” “Twenty one shift worked police officers (40-60 years old) were compared with an age-matched control group operating in the same environment. All subjects underwent overnight polysomnography. ... Obstructive sleep apnea was found in 8 shift workers (38%) ... and in 8 control volunteers (38% of the studied group). ... All breathing parameters, as measured by polysomnography, did not differ between the two groups. Our results do not confirm the hypothesis that chronic irregular work hours promote the occurrence of obstructive sleep apnea in subjects aged 40-60 years.”

Paciorek, Byśkiniewicz, Bielicki, and Chazan (2006) compared “intensity of sleep disordered breathing in standard nocturnal polysomnography (PSG) and diurnal PSG after night shift in [twenty-five] shift workers with obstructive sleep apnea syndrome.” “The mean apnea/hypopnea index (AHI) in diurnal PSG was [significantly] higher than AHI in nocturnal PSG, 47,8+/-27,4/h vs 38,0 +/-24,1/h respectively.”

Tanigawa et al. (2006) examined “whether a relationship between SDB and blood pressure/hypertension is more evident among shift workers than among day workers.” They “measured BP levels and oxygen desaturation index (by nocturnal pulse oximetry) among 253 male shift workers and 206 male day workers. The prevalence of SDB (3% oxygen desaturation index ≥ 10 and ≥ 15 per hour) in all subjects was 11.3% and 6.1%, respectively, with no statistical difference between shift and day workers. Systolic and diastolic BP levels were correlated with 3% oxygen desaturation index in all subjects after adjustment for potential confounding variables. This association was primarily observed among workers aged ≥ 40 years, more specifically older shift workers.”

Laudenska, Klawe, Tafil-Klawe, and Złomańczuk (2007) examined “the direct effect of night-work on the occurrence of obstructive apneas during sleep after a night shift in [eight] fast-rotating shift workers with sleep-related breathing disorders.” “In four of the 8 subjects, during sleep after a night-shift, an increase in apnea/hypopnea index was found. Night work significantly increased several breathing variables: total duration of obstructive apneas during REM sleep, mean duration of obstructive apneas during arousal, and apnea index during arousal.”

H. PERFORMANCE

An excellent introduction to this subject is provided by the proceedings of the symposium on the Effects of Diurnal Rhythm and Loss of Sleep on Human Efficiency, held in Strasbourg in July 1970, sponsored by the North Atlantic Treaty Organization, Division of Scientific Affairs (Colquhoun, 1972).

Higgins, Chiles, McKenzie, Iampietro, and Winget (1975) investigated "the effects of a 12-hour shift in the wake-sleep cycle on physiological and biochemical responses and on multiple task performance." "According to the subjective fatigue index, the total fatigue for the awake periods was not significantly changed; however, the times within days for greatest fatigue were altered and 9 days were required for a complete reversal of the daily pattern from shortest to longest mean re-phasal times, these were; heart rate, norepinephrine, epinephrine, potassium, sodium, internal body temperature, and 17-ketogenic steroids. Performance data ... suggest the following: (1) There was evidence of diurnal variation during the preshift period. (2) There were decrements on the day of the shift following the short sleep period. (3) Performance during the first 3 days following the shift was relatively high for most of the day but was relatively poor in the final session of the day. (4) Performance on the fourth through sixth post-shift days was average or above average for the experiment with relatively small variations among the five test sessions per day. (5) Performance on the seventh through ninth post-shift days was below average for the experiment and showed some evidence of a return to a diurnal cycling pattern with a new peak period of performance that reflected the 12-hour shift in the wake-sleep schedule."

Reinberg *et al.* described studies in which male shift workers and former shift workers volunteered to self-measure several times per 24 hours their oral temperature (OT) as well as right and left hand grip strength (HGS) best performance (Reinberg, Andlauer, Bourdeleau, Lévi, & Bicakova-Rocher, 1984; Reinberg *et al.*, 1988). "Mainly, but not exclusively, subjects with poor tolerance to shift work exhibited an internal desynchronization with a circadian period *tau* different from 24 hrs. which was the case for OT as well as right and left HGS; each could be different in *tau* between one another and from 24 hrs. These results suggest that oscillatory systems may be influenced by the neocortex apparently with difference between right and left side."

Smith and Miles (1986, 1987) examined "the acute effects of meals, noise and nightwork." They "showed that there was a post-meal impairment in detection of targets in a cognitive vigilance task. This was found both during the day and at night, although certain features of the results suggested that the day and night effects were not equivalent. Noise increased the number of false alarms but reduced the post-meal impairment in hit rate. Subjects with low levels of trait or state anxiety showed the greatest post-lunch impairments in performance, but this effect was reduced when the meal was eaten at night."

Campbell (1989) provided a review of human performance with relevant to shiftwork and focusing on "biological rhythms in the circadian range, and to a lesser extent, in the ultradian range." This information was folded into the report produced by the OTA (1991). Meanwhile, Monk (1990) noted that "Nightwork not only taps into the 'low ebb' of certain circadian performance rhythms, it also involves sleep disruption, social and domestic disruption, and the chronic equivalent of jet lag, all of which can radically affect performance and safety." He discussed "performance rhythms, their relationship to the circadian system and the sleep/wake cycle, and 'on-the-job' shiftworker performance." He also discussed "how chronobiological results concerning the human circadian

timekeeping system ('biological clock'), its response to changes in schedule, and its influence on performance ability can be used to improve shift worker wellbeing, safety and productivity." Costa et al. (1990) edited the book, *Shiftwork: Health, Sleep and Performance*, based upon the proceedings of the 9th International Symposium on Night and Shift Work held in Verona, Italy, in 1989.

Monk, Folkard, and Wedderburn (1996) provided a review of the shiftwork area that focused "on aspects of safety and productivity." They discussed "the situations in which shiftworker performance is critical, the types of problem that can develop and the reasons why shiftworker performance can be impaired. The review ends with a discussion of the various advantages and disadvantages of several shift rotation systems, and of other possible solutions to the problem."

Della Rocco and Cruz (1996) used the Multiple Task Performance Battery (MTPB) in a study of the 2-2-1 schedule used by Air Traffic Controllers in the United States. "Significant performance decrements were observed primarily on the night shift for both age groups. The older group demonstrated decrements in accuracy of recall on the code lock task following both rapid rotations during the 2-2-1 schedule."

Gilliland, Schegel, and Nesthus (1997) investigated "the effects on human operator performance of work shift (Day Shift vs. Mid shift), a specific antihistamine drug (4 mg of ChlorTrimeton® brand chlorpheniramine maleate), and time on task accompanying three successive drug doses spaced every four hours." "[C]hlorpheniramine maleate alone had a strong negative influence on a wide range of task performance and mood measures. There was a rather complex relationship between work shift and time on the shift such that performance and mood during the Day Shift tended to get better and during the Mid shift tended to get worse. No evidence was found that chlorpheniramine maleate and work shift combine to produce a multiplicative effect."

Porcù et al. (1997) "evaluated the effects of 20 mg of temazepam on daytime sleep, the subsequent levels of nocturnal alertness/sleepiness, and performance in a laboratory simulation of acute night shift." "Results showed that the ability to maintain wakefulness and to perform some visuo-attentive tasks were substantially maintained during the night. On the other hand, sleep tendency linearly increased during the night."

Reilly, Waterhouse, and Atkinson (1997) considered "issues relating to aging, the circadian body clock, and adjustment to altered sleep-wake schedules." "With aging there is an increased tendency towards morningness which is linked with difficulties in sleeping. The peak time and amplitude of normal circadian rhythms are altered. Tolerance of shiftwork can be linked with social factors as well as adaptation of the body clock."

Quera-Salva et al. (1997) "studied the performance and adaptability of 40 nurses, 20 on permanent day shift and 20 on permanent night shift with fast rotation of work and days off." They used a four choice reaction time and a memory test for seven letters. "Comparison of performance scores revealed that all nurses performed similarly on days off. Daytime nurses and fast-shifting night nurses had similar scores on work days, while nonshifting night nurses had significantly lower scores at work."

Axelsson et al. (1998) compared "12-hour shifts during weekends with 8-hour shifts during weekdays with respect to sleep, sleepiness, physical effort, and performance" at a power plant. (This is one of the complex schedules described in Miller, 2006). "There was no difference between 8- and 12-

hour shifts with respect to performance.”

Porcù, Bellatreccia, Ferrara, and Casagrande (1998) “evaluated the effects of a laboratory simulation of acute night-shift changes on sleepiness, vigilance and performance, using Maintenance of Wakefulness Test, Multiple Sleep Latency Test and three pencil and paper tests: Digit Symbol Substitution Test, ‘Deux Barrages’ Test and a 3-Letter Cancellation Task.” “Results showed that the ability to maintain wakefulness and to perform simple visuo-attentive tasks is substantially spared during the night. On the other hand, sleep tendency and performance on a more complex and monotonous task (Letter Cancellation Task) reveal, respectively, increasing sleepiness and degrading performance.”

Kelly et al. (1998) studied 24-hr. coverage by Mission Operations Directorate (MOD) personnel during Space Transportation System (STS, Space Shuttle) operations. “The initial results clearly support the need for further data collection during other STS missions to document baseline levels of alertness and performance during MOD shiftwork operations.”

Casagrande et al. (1999) examined the usefulness of pencil and paper tests of vigilance to assess attentional performance degradation due to sleep loss and/or inversion of the sleep-wake cycle. They “evaluated the sensitivity of a three-Letter Cancellation Task (3-LCT) in revealing nighttime variations of vigilance in a laboratory simulation of acute night shift, after a diurnal sleep with placebo (PLC) or temazepam (TMZ). ... Results show that the 3-LCT is sensitive to variations of vigilance occurring during a laboratory simulation of acute night shift. We also found some effects of TMZ, which in the first nocturnal session caused a slowing down of visuoattentive performance.”

Dula et al. (2001) tried to “determine whether working five serial night shifts in the emergency department results in a decline in physician performance as measured with an intelligence test,” using the Fluid Scale of the Kaufman Adolescent and Adult Intelligence Test (KAIT). “The mean day-shift KAIT score was 119.1 (SD=7.7), and the mean night-shift KAIT score was 107.2 (SD=10.2). This difference was significant, with the day-shift scores being statistically higher than the night-shift scores.”

Hart, Ward, Haney, Nasser, and Foltin (2003) examined “the effects of the central nervous system stimulant methamphetamine on psychomotor task performance, subjective effects, and food intake during shift work under laboratory conditions.” “When participants received placebo, psychomotor task performance and subjective effects were disrupted during the night shift, relative to the day shift. Changing shift conditions did not alter food intake significantly. Methamphetamine reversed performance and subjective-effects disruptions, and decreased food intake during the night shift.”

Rollinson et al. (2003) obtained “preliminary information on the neuropsychological performance of house officers at the beginning and end of a shift while they worked consecutive night shifts in the emergency department”. “The Delayed Recognition Span Test (number correct before first error) revealed significant deterioration from the beginning of the shift to the end of the shift. This represents an 18.5% decrease in visual memory capacity. There were no significant differences found for the other tests.”

Cruz et al. (2003) “directly compared clockwise (CW) and counterclockwise (CCW) rapidly rotating shiftwork schedules on measures of complex and vigilance task performance”. “A three-way, rotation condition by shift by session interaction for the active task composite scores and a rotation condition by shift interaction for the Bakan Vigilance Task indicated that effects of rotation condition

were modulated by shift type, such that on particular shifts, performance in the CCW rotation was actually better than in the CW rotation.”

Mauvieux et al. (2003) examined “the resistance and persistence of the circadian rhythm of temperature (T degree) and the sleep quality of athletic subjects and sedentary subjects engaged in night work, and attempt to explain the mechanisms that influence these differences.” A “physical training program seems to improve several mechanisms of the human biological system: amplitudes of circadian rhythms were increased and the circadian rhythm period was more resistant to an environment extreme (night work, shift work, sleep deprivation, or jet lag). To test this hypothesis, athletes and sedentary subjects who were engaged in regular night work were selected in the PSA Peugeot Citroën Automobiles Group in French Normandy country. ... The results revealed a large stability in the rhythm of circadian variation of T degree for the athletes: the amplitude was still large but for the sedentary subjects the amplitude of the T degree decreased and it was difficult to adjust a period on the rhythm of T degree. The stability and persistent quality of the athletes’ circadian rhythm was confirmed. We observed that the actigraphic sleep was greater for athletes than for sedentary subjects, and the acrophase time for the athletes was later than for the sedentary subjects during the night shift.”

Crowley, Lee, Tseng, Fogg, and Eastman (2004) assessed “performance, alertness, and mood during the night shift and subsequent daytime sleep in relation to the degree of re-alignment (re-entrainment) of circadian rhythms with a night-work, day-sleep schedule.” “The Neurobehavioral Assessment Battery showed that performance, sleepiness, and mood were better in the groups that re-entrained compared to the group that did not re-entrain, but there were no significant differences between the partial and complete re-entrainment groups.”

Cosenzo, Fatkin, and Branscome (2005) considered the U.S. Army Future Force and proposed “that a new approach be used when one is examining the effects of uncertainty on decision making by focusing on understanding how individuals assess situations and make decisions in addition to understanding the impact of situational elements.” “The second objective was to examine the effect of work shifts and cognitive uncertainty on performance in the same environment. Data were collected at an emergency operations center (EOC) because it is a realistic multi-task environment and the flow of information in an EOC is similar to that in a tactical operations center. Nineteen EOC operators completed a battery of stress and uncertainty questionnaires. The performance measure was the time required for the operator to complete an emergency call. Results showed that individual differences in coping with uncertainty were related to call time.”

Hart, Haney, Nasser, and Foltin (2005) created a simulated shift work to study the acute effects of the stimulant, methamphetamine, the effects of the hypnotic, zolpidem, and the combination. “When participants received placebo at both dosing times, performance on some psychomotor tasks (e.g., the digit-symbol substitution task) and on some measures of mood (e.g., ratings of ‘Energetic’) were disrupted during the night shift, relative to the day shift. Methamphetamine alone eliminated virtually all shift-related disruptions, while zolpidem alone and the drug combination produced few effects.”

Bonnefond et al. (2006) studied “work shift related interactions of age with sleep-wakefulness, performance, and social life.” “A representative sample of aircraft maintenance workers in a continuous three-shift system was studied by a questionnaire (n = 275) and an on-site field (n = 49)

study. ... Night shifts were related with shorter sleep, decreased performance, and increased sleepiness. Although subjective sleepiness was greatest among the youngest (25-34 years) age group during the morning and the night shifts, the increase of performance lapses was higher among the middle-aged (35-49 years) and senior (50-58 years) groups during the night shifts compared to the youngest age group. According to the questionnaire, older shiftworkers also tended to perceive more frequently that subjective sleepiness decreases their work performance during the morning and night shifts."

Thomas et al. (2006) "compared the amount of daily sleep and the cognitive performance in flight nurses working 12-hour evening versus 18-hour shifts during a 72-hour duty schedule." "Despite the decline in daily sleep during both duty schedules, no significant decline in the before versus after cognitive test scores were observed for either the 12- or 18-hour duty schedule."

De Valck et al. (2007) examined "simulator driving and subjective sleepiness after morning, afternoon, and night shifts and to compare these differences, as well as objective stress, between a fast-forward and a slow-backward rotating shift system." "Lane drifting was higher after a night shift than after an afternoon shift. No effect of rotation system on driving performance could be shown."

Driscoll, Grunstein, and Rogers (2007) reviewed literature "to provide evidence-based recommendations on the effect of various shift systems on neurobehavioural and physiological functioning and to identify areas which are lacking in appropriate evidence." "Overall, the review found there is insufficient evidence to support definitive conclusions regarding any of these factors. However, the analysis provides support for the use of forward rotating shift systems in preference to backward rotating shift systems, at least as far as 8-hour shifts are concerned." Lockley et al. (2007) found that "The weight of evidence strongly suggests that extended-duration work shifts significantly increase fatigue and impair performance and safety." "From the standpoint of both providers and patients, the hours routinely worked by health care providers in the United States are unsafe."

Santhi et al. (2007) hypothesized that "the circadian effect on cognitive functions magnifies with increasing sleep pressure, cognitive deficits associated with night work are likely to be most acute with extended wakefulness, such as during the transition from a day shift to night shift." "There was a nocturnal decline in cognitive processes, some of which were most pronounced on the first night shift. The nighttime decrease in visual search sensitivity was most pronounced on the first night compared with subsequent nights, and this was accompanied by a trend towards selective attention becoming 'fast and sloppy.' The nighttime increase in attentional lapses on the PVT was significantly greater on the first night compared to subsequent nights indicating an impaired ability to sustain focus. The nighttime decrease in subjective alertness was also greatest on the first night compared with subsequent nights."

Kirkpatrick et al. (2008) "examined methamphetamine-related mood, performance, and reinforcing effects during simulated shift work." "Night-shift work disrupted psychomotor task performance and some ratings of mood, especially on the first night. Consistent with this, participants chose to take methamphetamine significantly more often on the first night-shift night compared with the first day-shift day. Regardless of shift condition, however, participants selected markedly more methamphetamine doses before the work period than after it (73% versus 34%)."

Gander et al. (2008) "examined work patterns, sleep (actigraphy, diaries) and performance (psychomotor vigilance task [PVT] pre- and post-duty) of 28 anaesthesia trainees and 20 specialists across a two-week work cycle in two urban public hospitals." "Post-night shift performance was worse

than post-day shift performance ... At the end of night shifts, poorer performance was associated with longer shift length, longer time since waking, greater acute sleep loss, and more total work in the past 24 h. Specialists at both hospitals had scheduled clinical duties during the day and were periodically scheduled on call to cover after-hours services. On 8% of day shifts and 14% of day+call schedules, specialists were working with ≥ 2 h of acute sleep loss. ... Post-duty reaction times slowed linearly across consecutive duty days. Poorer post-duty performance was associated with greater acute sleep loss and longer time since waking, but better performance was associated with longer day shifts, consistent with circadian improvement in psychomotor performance across the waking day. ... Consistent with observations from experimental studies, the sleep loss of specialists across 12 consecutive working days was associated with a progressive decline in post-duty PVT performance. However, this decline occurred with much less sleep restriction (< 1 h per day) than in laboratory studies, suggesting an exacerbating effect of extended wakefulness and/or cumulative fatigue associated with work demands. For both trainees and specialists, robust circadian variation in PVT performance was evident in this complex work setting, despite the potential confounds of variable shift durations and workloads."

1. Models and Software

Knauth, Schwarzenau, Brockmann, and Rutenfranz (1982) presented a search algorithm "to generate all shift systems according to a given set of constraints, including physiological and social requirements." "The generated shift systems are weighted according to such criteria as the time distribution of the shifts, the length of the weekend leisure time and the regularity of the shift system. The use of this algorithm is restricted to the construction of shift systems for a maximum of five crews, as is usual in industry. A heuristic algorithm for the construction of more complex shift systems, as used in the services sector, is also described."

Folkard, Akerstedt, Macdonald, Tucker, and Spencer (1999) summarized "the development and refinement of the additive three-process model of alertness first published by Folkard and Akerstedt in 1987." They reviewed "some of the successes that have been achieved by the model in not only predicting variations in subjective alertness on abnormal sleep-wake schedules but also in accounting for objective measures of sleep latency and duration. Nevertheless, predictions derived from the model concerning alertness on different shifts, and over successive night shifts, are difficult to reconcile with published data on accident risk. In light of this, we have examined two large sets of alertness ratings with a view to further refining the model and identifying additional factors that may influence alertness at any given point in time. Our results indicate that, at least for the range of sleep durations and wake-up times commonly found on rotating shift systems, we may assume the phase of the endogenous circadian component of alertness (process C) to be 'set' by the time of waking. Such an assumption considerably enhanced the predictive power of the model and yielded remarkably similar phase estimates to those obtained by maximizing the post-hoc fit of the model. We then examined the manner in which obtained ratings differed from predicted values over a complete 8-day cycle of two, 12-hour shift systems. This revealed a pronounced 'first night compensation effect' that resulted in shift workers rating themselves as progressively more alert than would be predicted over the course of the first night shift. However, this appeared to be achieved only at the cost of lowered ratings on the second night shift. Finally, we were able to identify a 'time on shift' effect whereby, with

the exception of the first night shift, alertness ratings decreased over the course of each shift before showing a modest 'end effect.'”

Dijk, Duffy, and Czeisler (2000) provided an extensive review that demonstrated that “Quantification of the interaction between sleep homeostasis and circadian rhythmicity contributes to understanding age-related changes in sleep timing and quality.”

McDonald, Ramakrishna, and Schultz (2002) modeled “residents’ work hours and assess options to forthrightly meet Residency Review Committee-Internal Medicine (RRC-IM) requirements.” “Our electronic model is sufficiently robust to accurately estimate work hours on multiple and varied *rotations*. This model clearly demonstrates that it is very difficult to meet the RRC-IM work-hours limitations under standard fourth-night-call schedules with only four days off per month. We are successfully using our model to test proposed alternative scenarios, to overcome faculty misconceptions about resident work-hours ‘solutions,’ and to make changes to our call schedules that both are realistic for residents to accomplish and truly diminish total resident work hours toward the requirements of the RRC-IM.”

Kostreva, McNelis, and Clemens (2002) noted that “Czeisler et al. (1982) developed a set of circadian rhythm based guidelines intended to aid in designing such shiftwork schedules.” “This paper takes research one step further by testing such empirical criteria in a mathematical setting. The two-oscillator model of free-run human circadian rhythms developed by Kronauer et al. (1982) was modified to represent the circadian rhythms of a shiftworker on a pre-selected shiftwork schedule. Numerical simulations were used to compare the circadian rhythms produced from a variety of shiftwork schedules to the free-run rhythms. Shift schedules that resulted in circadian rhythms closest to the free-run rhythms were identified as preferred schedules. The numerical results supported Czeisler’s findings (1982), indicating the best shift schedules adopt a slow, forward-shifting rotation pattern, rotate shifts after 2-week periods and allow an average of 2 days off per week.”

Folkard and Lombardi (2004) described their “preliminary attempt to develop a Risk Index to estimate the risk of human error on different work schedules based on trends in the relative risk of accidents and injuries, rather than on hypothetical intervening variables such as alertness, fatigue, or performance on interpolated tasks.” “A simple Risk Index based on an additive model is developed on the basis of these trends, and we illustrate how it may be used to assess work schedules. Finally, we compare the results from this Risk Index with those from the UK HSE’s Fatigue Index and point out the discrepancies that emerge.” Åkerstedt, Folkard, and Portin (2004) summarized the “computer model for predicting alertness/performance in daily life.” “The model also includes prediction of psychomotor performance on various tasks, an identification of levels at which the risk of performance/alertness impairment start, as well as a prediction of sleep latency and time of awakening from sleep. The model is currently being used to evaluate work/rest schedules for navy, airline and railway applications. It is also used for teaching sleep/wake regulation and for generating research hypotheses.”

Mallis, Mejdal, Nguyen, and Dinges (2004) summarized “key features of seven biomathematical models reviewed as part of the Fatigue and Performance Modeling Workshop held in Seattle, WA, on June 13-14, 2002.” Mallis et al. noted that the model developers completed “a survey of the goals, capabilities, inputs, and outputs of their biomathematical models of alertness and performance. ... Survey responses revealed that models varied greatly relative to their reported goals and capabilities.

While all modelers reported that circadian factors were key components of their capabilities, they differed markedly with regard to the roles of sleep and work times as input factors for prediction: four of the seven models had work time as their sole input variable(s), while the other three models relied on various aspects of sleep timing for model input. Models also differed relative to outputs: five sought to predict results from laboratory experiments, field, and operational data, while two models were developed without regard to predicting laboratory experimental results. All modelers provided published papers describing their models, with three of the models being proprietary."

Dijk and Larkin (2004) noted that "Most current models, including the Circadian Alertness Simulator (CAS), derive from the two-process theory of sleep regulation." "In these models, performance and fatigue are determined by a homeostatic process that depends solely on sleep/wake history, and a circadian process, driven by the biological clock. These models assume: 1) performance capability recovers in an exponential manner during sleep; 2) the homeostatic and circadian processes are additive. Current evidence suggests that both assumptions require modification. An attractive feature of the CAS is that it computes alertness curves for individuals, based on individual sleep/wake histories and other data. However, statistical evaluation is usually based on group data, with few performance metrics. As in other models, there is no substantive theory to connect the alertness computation with specific cognitive or psychomotor functions."

Folkard and Åkerstedt (2004) reviewed "the available literature on shiftwork safety in which real measures of accidents or injuries could be pinpointed in time and in which the a priori risk appeared to be constant." "Three main problems for the models emerged from this review: 1) risk was significantly higher on the afternoon shift than on the morning shift; 2) the dominant peak in risk over the course of the night shift occurred at about midnight; and 3) risk increased substantially over spans of four successive nights."

Hursh et al. (2004) described the development of the Sleep Performance Model (SPM) and the subsequent Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) Model. They described "the working fatigue model as it is being developed by the DOD laboratories ... Extensions of the SAFTE Model to incorporate dynamic phase adjustment for both transmeridian relocation and shift work are described."

Moore-Ede et al. (2004) described the Circadian Alertness Simulator (CAS), which "was developed as a practical tool for assessing the risk of diminished alertness at work." "Applications of CAS include assessment of operational fatigue risk, work schedule optimization, and fatigue-related accident investigation. Based on the documented work schedules of employees, sleep and alertness patterns are estimated and a cumulative fatigue score is calculated. ... The free parameters of the algorithms were optimized using over 10,000 d of sleep and alertness data sets collected from transportation workers performing their regular jobs. The validity and applicability of the CAS fatigue score was then tested using work/rest and accident data from three trucking operations."

Roach, Fletcher, and Dawson (2004) described "the Fatigue Audit InterDyne (FAID), can be used to quantify the work-related fatigue associated with any duty schedule using hours of work (i.e., start/end times of work periods) as the sole input." "The objectives of the current paper were to: 1) describe the background and conceptual basis of FAID; 2) present FAID-based predictions for four of the scenarios; and 3) discuss the advantages of, and possible improvements to, FAID."

Schomann, Stapel, Nickel, Eden, and Nachreiner (2004) extended "an existing computer programme for the evaluation and design of shift schedules (BASS 3) by integrating workload as well as

economic aspects.” “The new version of the computer programme (BASS 4) can now simultaneously take into account numerous ergonomic, legal, agreed and economic criteria for the design and evaluation of working hours.” Schomann, Giebel, and Nachreiner (2006) used BASS 4 to produce “a less sophisticated Working-Hours-Risk Index for assessing the quality of work schedules (including flexible work hours) to indicate risks to health and wellbeing.” “The results of a validation study show that this risk index seems to be a promising indicator for predicting risks of health complaints and wellbeing. The purpose of the Risk Index is to simplify the evaluation process at the shop floor and provide some more general information about the quality of a work schedule that can be used for triggering preventive interventions. Such a risk index complies with practitioners’ expectations and requests for easy, useful, and valid instruments.”

Folkard, Lombardi, and Spencer (2006) “integrated the published evidence on three independent sources of data that allow estimations of the trend in risk over a 24 h day, over the course of the night shift, and across the three different (8 h) shifts” (see also Folkard, 2006). “Despite potential confounders, maximum risk (i.e., acrophase = peak time) estimates across these three trends showed a remarkable consistency, with all three estimates occurring at about midnight, although the amplitude estimates varied considerably. The best estimate of the amplitude of the circadian rhythm in risk would appear to be that based on trend over the three (8 h) shifts, as this trend is the least confounded. The estimated acrophase (peak time) in risk appeared earlier than would be predicted from consideration of the circadian rhythm in alertness, fatigue, or performance on simple interpolated tasks, such as reaction time or performance on the Psychomotor Vigilance Test.” “A review has been carried out of trends in risk related to shift work, and this has enabled the final version to incorporate two separate indices, one related to fatigue (the Fatigue Index) and the other to risk (the Risk Index). While the two indices are similar in many respects they diverge in others. The main differences are due to the different trends with respect to time of day in fatigue and risk. The index has been implemented in the form of a spreadsheet, the design of which has incorporated feedback from users of the previous index.” Folkard and Lombardi (2006) then used the model to calculate “The estimated risks of an incident for various standard work schedules.” “The estimated risk of an injury or accident associated with any given number of weekly work hours varies substantially depending on how work hours are comprised. The risk depends on the length and type of shift, as well as the frequency of rest breaks.”

Eddy and Hursh (2006) described the Fatigue Avoidance Scheduling Tool (FASTTM), the Windows[®] implementation of SAFTE. The software allows a user to predict cognitive performance and effectiveness based on the timing and amount of sleep an individual or team receives prior to and during a mission.

I. RESEARCH NEEDS

Kogi (2005) reviewed “Research needs in identifying preventive measures dealing with working time arrangements and associated sleep problems.” “These needs are based on the recognition of a range of risk factors for health involving disturbed circadian rhythms leading to various levels of sleep deficits. The review takes account of recent joint change approaches that address both working time arrangements and various relevant intervening factors. As examples of such approaches, voluntary industry-based guidelines for improving shift work are examined. Also reviewed is evidence indicating the effects of improved working time arrangements and sleep hygiene on the tolerance of workers

working irregular shifts. Trends in action-oriented risk assessment are further discussed as the effects on health and sleep of these workers may be modified by complex aspects related to working situations, family and social conditions, personal characteristics and social support. Generally relevant are not only the relationships between sleep-affecting factors and health, but also advances in taking the various support measures. The effective use of participatory steps is found important in dealing with working time arrangements and associated health and sleep problems together. It is thus considered important to study (a) the efficacy of joint change approaches addressing complex sleep and health factors, (b) effective procedures for action-oriented health risk assessment in various work life situations, and (c) the relevance of innovative participatory steps to improving health and tolerance of workers. Future research topics mentioned by the participants of the international symposium on night and shift work held in Santos in 2003 are presented, and international efforts to promote research into these aspects in field conditions are discussed. Interactive research involving local people appears crucial."

Belenky and Van Dongen (2005) planned to "conduct laboratory and field studies of sleep loss and performance in normal humans." "These studies will provide the scientific basis for the effective management of sleep to sustain performance in the operational environment, including all 24x7 operations, extended work hours, and shiftwork. They will improve effectiveness, productivity, safety, health and well-being in military and civilian operations, reducing the likelihood of fatigue-related error, incident, accident or catastrophe."

J. METHODOLOGIES

Krueger and Englund (1985) described "diverse methodologies used in sustained work/sustained operations (SUSOPS) laboratory and field research." Redmond and Hegge (1985) introduced the wrist activity monitor (actigraphy) as an important tool. "Monitoring motor activity provides an important index of sleep, rest, and activity in field studies of sustained operations, shift-work schedules, and sleep deprivation."

Colquhoun et al. (1988) proposed and used a methodology for a "large-scale shipboard study of merchant mariners on extended voyages" with details "of the techniques used to measure sleep and activity, and temporal variations in a range of physiological and psychological parameters. A summary of the data collected in the study is provided as a reference point for the reports on the different aspects of the results that follow in subsequent articles."

Shinkai et al. (1993) examined "the validity of salivary cortisol for monitoring circadian rhythm variation in adrenal activity during shiftwork." "[S]alivary cortisol appears to be an excellent measure for monitoring circadian rhythm variation in adrenal activity in healthy individuals during shiftwork."

Barton et al. (1995) introduced the Standard Shiftwork Index (SSI), "which is a set of questionnaires designed for comparing the effects of different types of shift system on large groups of workers." "It includes measurements of psychological ill-health, physical ill-health, chronic fatigue, social and domestic disruption, attitudes towards shiftwork, sleep quality and sleep habits." The SSI and the accompanying manual were published by the Shiftwork Research Team of the MRC/ESRC Social and Applied Psychology Unit, with Dr. Simon Folkard as its leader.

Waterhouse, Minors, and Redfern (1997) discussed masking. They noted that "Work using 'constant routines' and 'purification' methods indicates that the internal dissociation results from differences between variables in the relative contribution of exogenous ('masking') effects to the

measured rhythm. These results indicate, therefore, there is no need to postulate the presence of more than one body clock which is responsible for the endogenous component of a circadian rhythm, and that heavily masked circadian rhythms will be poor indicators of the rate of adjustment of this clock. Nevertheless, it will be the measured rhythm that describes most directly the disruption to circadian rhythmicity caused by changed sleep/wake schedules.”

Fukuda et al. (1999) used “a standard questionnaire, repetitive self-assessment of subjective symptoms and daily behavior at short intervals, and a continuous recording of such objective indices as physical activity and heart rate.” “A potential problem lies in the fact that field studies that use such measures tend to produce a mass of data, and are thus faced with the accompanying technical problem of analyzing such a large amount of data (time, effort and cost). To solve the data analysis problem, we developed an automated data processing system. Through the use of an image scanner with a paper feeder, standard paper, an optical character recognition function and common application software, we were able to analyze a mass of data continuously and automatically within a short time. Our system should prove useful for field studies that produce a large amount of data collected with several different kinds of measuring devices.”

Delafosse et al. (2000) compared actigraphy to polysomnography for sleep evaluation. “Actigraphy seems to be an efficient, low cost and easy method for measuring total sleep time as well as for assessing the inability of nurses to adapt to permanent night shift work.” Czeisler (2001) used a wrist device to record “ambient light level and wrist actigraphy” of subjects prior to a sleep deprivation jet-lag protocol; and developed and conduct near-real-time analysis of these sleep and light exposure data. Data were to be “analyzed using our most recent mathematical model that predicts waking alertness and neurobehavioral performance as well as circadian phase from activity (sleep-wake) and light history.”

Smith et al. (2001) examined “the measurement properties of [the SSI] in an industrial sample of primarily male shiftworkers.” “We found that all scales had acceptable reliabilities (alphas). The confirmatory factor analyses revealed that the chronic fatigue, coping, job satisfaction, and sleep scales are the weakest psychometrically, and the anxiety, personality (extraversion, neuroticism), general health, and physical health scales are the strongest psychometrically. Using item response theory analyses, we found that the scales overall are generally adequate measures of their underlying constructs, although many items should be altered or omitted.”

Knutsson (2004) reviewed “a number of common methodological issues which are of relevance to epidemiological studies in this area of research. It discusses conceptual problems regarding the use of the term ‘shift work,’ and it underscores the need to develop models that explain the mechanisms of disease in shift workers.”

Tucker and Knowles (2008) reviewed the published SSI literature and evaluated “the extent to which the results of these publications support the model underpinning the SSI.” “The analysis indicated support for parts of the SSI model, particularly in relation to the impact of shift systems design on individual well-being, as well as the role of individual factors (e.g., personality, coping style). However, evidential support for the model as a whole is incomplete.”

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