NPS-OR-07-001

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Fatigue in Military Operational Environments: An Annotated Bibliography

by

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July 2007

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Prepared for: Program Executive Office Soldier
SFAE-SDR
5901 Putnam Road, Bldg. 328
Ft. Belvoir, VA 22060-5422

NAVAL POSTGRADUATE SCHOOL
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This report was prepared for and funded by Program Executive Office Soldier, SFAE-SDR, 5901 Putnam Road, Bldg. 328, Ft. Belvoir, VA 22060-5422.

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 2007

3. REPORT TYPE AND DATES COVERED
Technical Report

4. TITLE AND SUBTITLE:
Fatigue in Military Operational Environments: An Annotated Bibliography

5. FUNDING NUMBERS

6. AUTHOR(S):
Nita Lewis Miller, Lawrence G. Shattuck, and Panagiotis Matsangas

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Operations Research Department, Naval Postgraduate School,
Monterey, CA 93943-5219

8. PERFORMING ORGANIZATION REPORT NUMBER
NPS-OR-07-001

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Program Executive Office Soldier, SFAE-SDR, 5901 Putnam Road, Bldg. 328,
Ft. Belvoir, VA 22060-5422

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT (maximum 200 words)

Research involving sleep and fatigue in military operations has been conducted for many years. Indeed, following nearly every major military engagement or conflict, reports are published which detail the effects of sleep deprivation on human performance. Unfortunately, many of these reports never make it to the scientific literature, and are published instead as technical reports. Following an extensive search of all available data sources including open scientific journals and electronic resources (e.g., military, psychological, medical, pharmacological, and biomedical journals or electronic resources), the Defense Technical Information Center (DTIC), and other government information sources, this annotated bibliography represents an effort to put together a comprehensive, although not exhaustive, description of all such studies that were conducted between the years 1983 and 2006. The bibliography covers research involving military personnel in operational environments including combat, observations during military exercises, findings on fatigue in laboratory settings, including with simulated military tasks, findings on fatigue in simulations, and findings on sustained (SUSOPS) and continuous operations (CONOPS). When available and deemed appropriate, the original abstracts from the citations were used. If no abstract was available from the original work, the authors developed one.

14. SUBJECT TERMS
Fatigue, sleep deprivation, sleep debt, military operations, circadian rhythms in operational environments, degraded performance, safety

15. NUMBER OF PAGES
89

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
UU

Table of Contents

Introduction

This work is an annotated bibliography on fatigue in military environments. The references cited herein address the effects of fatigue and sleepiness due to sleep deprivation. The bibliography focuses specifically on the effects of fatigue on performance in military populations and is divided into the following categories:

- Military personnel in operational environments including combat
- Observations during military exercises
- Findings on fatigue in laboratory settings, including with simulated military tasks
- Findings on fatigue in simulations
- Findings on sustained (SUSOPS) and continuous operations (CONOPS)

The articles cover the time period from 1983 through 2006.

Approach

The references cited in the presented bibliography were obtained from numerous and widely scattered sources such as the open scientific journals and electronic resources (e.g., military, psychological, medical, pharmacological, and biomedical journals or electronic resources), the Defense Technical Information Center (DTIC), and other government information sources. All citations are in English, but they include some foreign language reports translated into English. All references are appropriate for public release.

The present work focuses on the effects of sleep and circadian rhythms and does not include literature on combat or battle stress per se. Finally, anecdotal reports from specific operations are included since they may be useful for establishing a general view of warfighter performance in the operational environment.

The primary purpose of the present work was to gather relevant literature from disparate sources, giving a synopsis of the main points to be gleaned from each citation. The annotations in this paper were derived from the abstracts in the journal articles or reports. When available and deemed appropriate, the original abstracts from the citations were used. If no abstract was available from the original work, the authors developed one. This annotated bibliography was written to inform readers interested in learning more about fatigue and sleep issues in military environments.

Results

The following conclusions were derived from this effort:

- In general, there are significantly more studies on fatigue in aviation (military and civil) than in other operational environments.

- Few citations are available that compare individual branches to others, for example, comparing Naval aviation to UAV operations.
- There are few citations that examine fatigue in healthy populations during military operations (that is, populations not experiencing chronic fatigue syndrome, fatigue due to stress, pathological issues, etc.)

The results and categorizations of the literature gathered to date are depicted in the following table.

Category	Subcategory	Number of References
Army		30
	General	11
	Training	5
	Special Forces	4
	Armored Infantry	1
	Aviation	6
	Mechanized Infantry	1
	Artillery	2
Navy		24
	Training	1
	Seals	4
	Naval Aviation	11
	Surface Ships	5
	Submarines	3
Marine Corps		3
Air Force		16
	General	3
	Long-Haul Transportation/Airlift	5
	Helicopters	1
	Fighting Aircraft	3
	Bombers	2
	Air Traffic Control	1
	UAV Operations	1
Coast Guard		4
Military Laboratory/Simulator		18
Civilian		23
	Civilian Laboratory Research	12
	Civilian Aviation	6
	Civilian Ground Transportation	1
	Merchant Marine	4
Reviews		21
Other		6

Table 1: Reference Categories

The following diagram depicts the proportions by category for the citations referenced in this report.

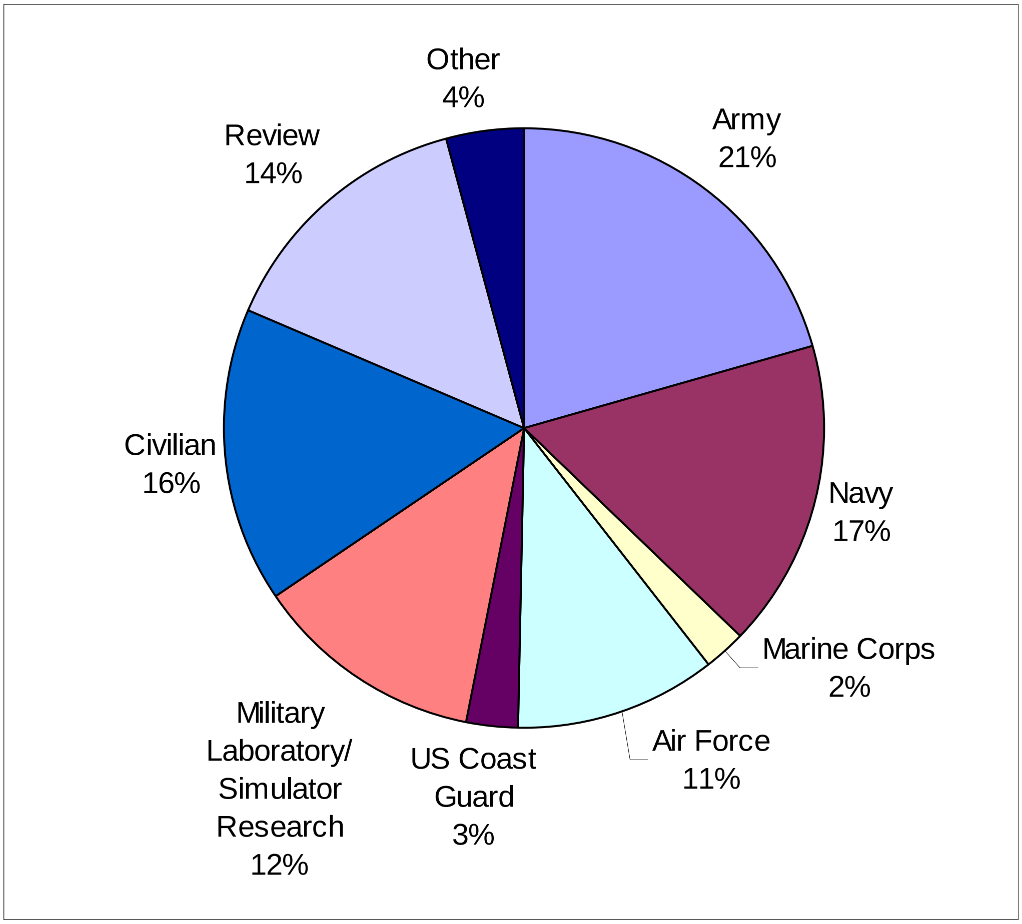

Figure 1: Proportions by Category

Alphabetical Listing of Citations

The following alphabetical listing by first author serves as a quick reference guide for this annotated bibliography. Full references and abstracts follow in the "Annotated Bibliography" section.

A

[1]. (Andrews, 2004)
[2]. (Angus and Heslegrave, 1985)
[3]. (Arendt, Middleton, Williams, Francis, and Luke, 2006)

B

[4]. (Babkoff, Kelly, and Naitoh, 2001)
[5]. (Babkoff and Krueger, 1992)
[6]. (Baird, Coles, and Nicholson, 1983)
[7]. (Baranski, Cian, Esquivie, Pigeau, and Raphel, 1998)
[8]. (Baranski, Gil, McLellan, and Moroz, 2002)
[9]. (Belenky, 1997)
[10]. (Belenky, Krueger, Balkin, Headley, and Solick, 1987)
[11]. (Bell, Ducharme, Drolet, and Boyne, 2005)
[12]. (Belland and Bissell, 1994)
[13]. (Blassingame, 2001)
[14]. (Bonnet, 1991)
[15]. (Bonnet, Gomez, Wirth, and Arand, 1995)
[16]. (Bourgeois-Bougrine, Cabon, Gounella, Mollard, and Coblemetz, 2003)
[17]. (Brictson and Young, 1980)
[18]. (Buguet, 1995)

C

[19]. (Caldwell, 1997)
[20]. (Caldwell, 2002)
[21]. (Caldwell, 2003)
[22]. (Caldwell, 2005)
[23]. (Caldwell and Caldwell, 2005)
[24]. (Caldwell, Caldwell, Brown, and Smith, 2004)
[25]. (Caldwell, Caldwell, Brown, Smythe, Smith, Mylar, Mandichak, and Schroeder, 2003)
[26]. (Caldwell, Caldwell, Colon, Ruyak, Ramspott, Sprenger, and Jones, 1998)
[27]. (Caldwell, Caldwell, and Roberts, 2002)
[28]. (Caldwell and Gilreath, 2002)
[29]. (Caldwell, Gilreath, Erickson, and Smythe, 2000)
[30]. (Caldwell, Gilreath, and Norman, 1999)

[31]. (Caldwell, Jones, Caldwell, Colon, Pegues, Iverson, Roberts, Ramspott, Sprenger, and Gardner, 1997)
[32]. (Caldwell and LeDuc, 1998)
[33]. (Cauter and Buxton, 2000)
[34]. (Chaiken, Barnes, Harville, Miller, Dalrymple, Tessier, Fischer, and Welch 2004)
[35]. (Chidester, 1986)
[36]. (Co, Gregory, Johnson, and Rosekind, 1999)
[37]. (Comperatore, Bloch, and Ferry, 1999)
[38]. (Comperatore, Kingsley, Kirby, and Rivera, 2001)
[39]. (Comperatore, Kirby, Bloch, and Ferry, 1999)
[40]. (Comperatore and Rivera, 2003)

D

[41]. (DeJohn, and Reams, 1992)
[42]. (DeJohn, Shappell, and Neri, 1992)
[43]. (Doheney, 2004)
[44]. (Driskell and Mullen, 2005)

E

[45]. (Evans, Mackie, and Wylie, 1991)

F

[46]. (Ferrer, Bisson, and French, 1995)
[47]. (Foo, How, Siew, Wong, Vijayan, and Kanapathy, 1994)
[48]. (French, Bisson, Neville, Mitcha, and Storm, 1994)

H

[49]. (Hardaway and Gregory, 2005)
[50]. (Harville, Barnes, and Elliott, 2004)
[51]. (Haslam, 1985)
[52]. (Horn, Thomas, Marino, and Hooper, 2003)
[53]. (Horne and Reyner, 1996)
[54]. (How, Foo, Low, Wong, Vijayan, Siew, and Kanapathy, 1994)
[55]. (Huffman, Adler, Calhoun, and Castro, 2001)

K

[56]. (Kamimori, Johnson, Thorne, and Belenky, 2005)
[57]. (Kavanagh, 2005)
[58]. (Kelly, Grill, Hunt, and Neri, 1996)
[59]. (Kenagy, Bird, Webber, and Fischer, 2004)
[60]. (Kenney and Neverosky, 2004)

[61]. (Killgore, Balkin, and Wesensten, 2006)
[62]. (Krueger, 1989)
[63]. (Krueger, 1991)
[64]. (Krueger and Barnes, 1989)
[65]. (Krueger, Cardenales-Ortiz, and Loveless, 1985)

L

[66]. (LaJambe, Kamimori, Belenky, and Balkin, 2005)
[67]. (LaJambe, Sing, Thorne, Balkin, Belenky, and Wesensten, 2003)
[68]. (Larsen, 2001)
[69]. (Lavie, 1986)
[70]. (LeDuc and Caldwell, 1998)
[71]. (LeDuc, Caldwell, and Tuyak, 2000)
[72]. (LeDuc, Greig, and Dumond ,2005)
[73]. (LeDuc, Riley, Hoffman, Brock, Norman, Johnson, Williamson, and Estrada, 1999)
[74]. (Lieberman, Bathalon, Falco, Morgan, Niro, and Tharion, 2005)
[75]. (Lieberman, Niro, Tharion, Nindl, Castellani, and Montain, 2006)
[76]. (Lieberman, Tharion, Shukitt-Hale, Speckman, and Tulley, 2002)
[77]. (Luna, French, and Mitcha, 1997)

M

[78]. (Majors, 1984)
[79]. (McLellan, Bell, and Kamimori, 2004)
[80]. (McLellan, Kamimori, Bell, Smith, Johnson, and Belenky, 2005)
[81]. (McLellan, Kamimori, Voss, Bell, Cole, and Johnson, 2005)
[82]. (Meyer and DeJohn, 1990)
[83]. (Miller, 2005)
[84]. (Miller, Smith, and McCauley, 1999)
[85]. (Murphy, 2002)
[86]. (Myles and Romet, 1987)

N

[87]. (Naitoh, 1989)
[88]. (Naitoh and Angus, 1987)
[89]. (Naitoh, Englund, and Ryman, 1986)
[90]. (Naitoh, Englund, and Ryman, 1987)
[91]. (Naitoh, Kelly, and Babkoff, 1990)
[92]. (Naitoh, Kelly, and Babkoff, 1992)
[93]. (Naitoh, Kelly, and Englund, 1990)
[94]. (Naitoh and Ryman, 1985)
[95]. (Neri and Shappell, 1993)
[96]. (Neri and Shappell, 1994)

[97]. (Neri, Shappell, and DeJohn, 1992)
[98]. (Neville, Bisson, French, Boll, and Storm, 1994)
[99]. (Nicholson, 1984)
[100]. (Nicholson, Roth, and Stone, 1985)
[101]. (Nguyen, 2002)

P

[102]. (Paley and Tepas, 1994)
[103]. (Patton, Vogel, Damokosh, and Mello, 1987)
[104]. (Paul, Pigeau, and Weinberg, 1998)
[105]. (Paul, Pigeau, and Weinberg, 2001)
[106]. (Pigeau, Angus, and O'Neil, 1995)
[107]. (Pilcher and Huffcutt, 1996)
[108]. (Pleban and Mason, 1996)
[109]. (Pleban, Valentine, Penetar, Redmond, and Belenky, 1990)

Q

[110]. (Quant, 1992)

R

[111]. (Rosekind, Co, Gregory, and Miller, 2000)
[112]. (Rosekind, Gander, Miller, Gregory, Smith, Weldon, Co, McNally, and Lebacqz, 1994)
[113]. (Rosekind, Gregory, Co, Miller, and Dinges, 2000)
[114]. (Rosenberg and Caine, 2001)
[115]. (Russo, Escolas, Santiago, Thomas, Sing, Thorne, Holland, Johnson, Redmond, and Hall, 2002)
[116]. (Russo, Kendall, Johnson, Sing, Thorne, Escolas, Santiago, Holland, Hall, and Redmond, 2005)
[117]. (Russo, Sing, Kendall, Johnson, Santiago, Escolas, Holland, Thorne, Hall, Redmond, and Thomas, 2005)
[118]. (Russo, Sing, Santiago, Kendall, Johnson, Thorne, Escolas, Holland, Hall, and Redmond, 2004)

S

[119]. (Samel, Vejvoda, and Maass, 2004)
[120]. (Sanquist, Raby, Forsythe, and Carvalhais, 1997)
[121]. (Sanquist, Raby, Maloney, and Carvalhais, 1996)
[122]. (Sawyer, 2004)
[123]. (Schultz and Miller, 2004)
[124]. (Shappell and Neri, 1993)
[125]. (Shappell, Neri, and DeJohn, 1992)

[126]. (Sharkey, Fogg, and Eastman, 2001)
[127]. (Shen, Botly, Chung, Gibbs, Sabanadzovic, and Shapiro, 2006)
[128]. (Simons and Valk, 1999)
[129]. (Skiller, Booth, Coad, and Forbes-Ewan, 2005)
[130]. (Spinweber and Johnson, 1983)
[131]. (Steele, Kobus, Banta, and Armstrong, 1989)
[132]. (Stoner, 1996)
[133]. (Symons, VanHelder, and Myles, 1988)

T

[134]. (Takeyama, Itani, Tachi, Sakamura, Murata, Inoue, Takanishi, Suzumura, and Niwa, 2005)
[135]. (Tharion, Shukitt-Hale, and Lieberman, 2003)
[136]. (Thompson, Lopez, Hickey, DaLuz, and Caldwell, 2006)
[137]. (Thompson and Tvaryanas, 2006)
[138]. (Treadwell, 1997)

W

[139]. (Wesensten, Belenky, Thorne, Kautz, and Balkin, 2004)
[140]. (Westcott, 2005)
[141]. (Whitmore, Doan, Heintz, Hurtle, Kisner, and Smith, 2004)
[142]. (Whitmore, Hickey, Doan, Harrison, Kisner, Beltran, McQuade, Fischer, and Marks, 2006)
[143]. (Williams, Streeter, and Kelly, 1998)

Annotated Bibliography

[1] Andrews, C. H. (2004). The relationship between sleep regimen and performance in United States Navy recruits. Operations Research, Naval Postgraduate School, Monterey, CA, 111.

> Purpose of this study was to determine the impact of the new eight-hour sleep regimen on U.S. Navy recruits at "boot camp" using standardized test scores as a performance measure. During the 1980s, the sleep regimen was decreased to 6 hours of sleep per night. In 2002, a decision was made to give U.S. Navy Recruits an additional two hours of sleep per night. This latest modification was selected to coincide with the acknowledged adolescent/young adult circadian rhythms. One year of data with the eight-hour sleep regimen is compared to two separate years when only six hours of sleep was allowed. Results show that there is a significant difference, F(2, 33) = 29.82, p <.0001, between the test scores of Recruits receiving 6-hours of sleep and 8-hours of sleep. On average test scores rose by 11 percent with the additional sleep.

[2] Angus, R. G. and Heslegrave, R. J. (1985). "Effects of sleep loss on sustained cognitive performance during a command and control simulation." Behavior Research Methods, Instruments, and Computers **17**(1): 55-67.

> The study measures performance on a continuous basis in a computerized laboratory environment. During a 54-h period of wakefulness, 12 female university students were required to continuously monitor and act upon information being transmitted over a communication network while their performance on cognitive tests was continuously evaluated. The results show that the cognitively demanding environment produces significantly greater mood and performance decrements as a function of sleep loss than other, less demanding studies have found.

[3] Arendt, J., Middleton, B., Williams, P., Francis, G., and Luke, C. (2006). "Sleep and Circadian Phase in a Ship's Crew." Journal of Biological Rhythms **21**(3): 214-221.

> The study investigated sleep (by actigraphy) and the adaptation of the internal clock in watch standers compared to normal day workers. Fourteen watch standers, 4 h on, 8 h off (0800-1200/2000-2400 h, 1200-1600/ 2400-0400 h, 1600-2000/0400-0800 h) (fixed schedule, n=6; rotating by delay weekly, n=8), and 12 day workers participated during a voyage from the United Kingdom to Antarctica. They kept daily sleep diaries and wore wrist monitors for continuous recording of activity. Sleep parameters were derived from activity using the manufacturer's software and analyzed by repeated-measures ANOVA using SAS 8.2. Sequential urine samples were collected for 48 h weekly for 6-sulphatoxymelatonin measurement as an index of circadian rhythm timing. Individuals working watches of 1200-1600/2400-0400 h and 1600-2000/ 0400-0800 h had 2 sleeps daily, analyzed separately as main sleep (longest) and 2nd sleep. Main sleep duration was shorter in watch standers than in day workers (p<0.0001). Objective sleep quality was significantly compromised in rotaters compared to both day workers and fixed watch keepers, the most striking

comparisons being sleep efficiency (percentage desired sleep time spent sleeping) main sleep ($p<0.0001$) and sleep fragmentation (an index of restlessness) main sleep ($p<0.0001$). The 2nd sleep was substantially less efficient than was the main sleep ($p<0.0001$) for all watch standers. There were few significant differences in sleep between the different watches in rotating watch standers. Circadian timing remained constant in day workers. Timing of the 6-sulphatoxymelatonin rhythm was later for the watch of 1200-1600/2400-0400 h than for all others (1200-1600/ 2400-0400 h, 5.90±0.85 h; 1600-2000/0400-0800 h, 1.5±0.64 h; 0800-1200/ 2000-2400 h, 2.72±0.76 h; days, 2.09±0.68 h [decimal hours, mean±SEM]: ANOVA, $p<0.01$). This study identifies weekly changes in watch time as a cause of poor sleep in watch standers. The most likely mechanism is the inability of the internal clock to adapt rapidly to abrupt changes in schedule.

[4] Babkoff, H., Kelly, T., and Naitoh, P. (2001). "Trial-to-trial variance in choise reaction time as a measure of the effects of stimulants during sleep deprivation." Military Psychology **13**(1): 1-16.

Thirty-six male students in the U.S. Navy Basic Underwater Demolition and Seal (BUDS) training program took part in this double-blind experiment. Performance stability, as assessed by trial-to-trial variance in a four-choice reaction time (RT) task, was tested around the clock during 64 hr of sleep deprivation, and the findings support the conclusion that sleep loss interacts with circadian rhythms to cause further deterioration in performance stability. The subjects were administered methylphenidate, pemoline, and a placebo 16 hr into a 64-hr sleep-deprivation protocol. Performance stability deteriorated significantly, especially during the circadian nadirs. Sleep deprivation increased trial-to-trial variance more than it increased the mean correct RT. In addition, this measure demonstrated differing effects of the 2 drug regimens. Pemoline, at a dose of 37.5 mg every 12 hr, significantly reduced the overall average effects of sleep loss on performance stability during the first 24 hr of drug administration. Pemoline also reduced circadian-related instability in performance throughout the study. Methylphenidate, at a dose of 10 mg every 6 hr, counteracted circadian-related instability in performance during the first 24-hr period of drug administration (16–40 hr of sleep deprivation) but not during the second 24-hr period (40–64 hr of sleep deprivation). Methylphenidate did not significantly affect the overall average effects of sleep loss on performance stability. Thus, trial-to-trial variance appears to be a valuable measure for elucidating stimulant effects during sleep deprivation.

[5] Babkoff, H. and Krueger, G. P. (1992). "Use of stimulants to ameliorate the effects of sleep loss during sustained performance." Military Psychology **4**(4): 192-205.

> Review of the use of stimulants in the field, as depicted in studies by Walter Reed Army Institute of Research (WRAIR), Naval Aerospace Medical Research Laboratory (NAMRL), and Naval Health Research Center (NHRC). Furthermore, methodological questions and testing procedures are discussed.

[6] Baird, J. A., Coles, P. K. L., and Nicholson, A. N. (1983). "Human factors and air operations in the South Atlantic Campaign: discussion paper." Journal of the Royal Society of Medicine **76**: 933-937.

> The paper discusses findings of flying hours workload and disturbed sleep in air operations during South Atlantic Campaign. During the operation there was an extensive use of hypnotics (temazepam) by air crews. The workload was depending on aircraft type and mission. Maritime reconnaissance posed a significant load of flying hours (100-h per two weeks, whereas aircrews of other missions were reaching 100-h per month). The same happened in long-haul transportation (the Hercules crews flying hours increased by 25%). The helicopter crews flew up to 10-h daily (at maximum 120-h per month whereas the peacetime maximum was 75-h).

[7] Baranski, J. V., Cian, C., Esquivie, D., Pigeau, R. A., and Raphel, C. (1998). "Modafinil during 64 hour of sleep deprivation: Dose-related effects on fatigue, alertness, and cognitive performance." Military Psychology **10**(3): 173-193.

> The study investigates the relative effects of three doses of modafinil on fatigue and cognitive performance in a 64-h sleep deprivation experiment. Results showed that 300 mg of modafinil in a 24-h period (100 mg every 8-h) maintained cognitive performance at or near baseline levels throughout the sleep deprivation period, 150 mg provided some maintainance of performance, and 50 mg was not substantively different from placebo.

[8] Baranski, J. V., Gil, V., McLellan, T. M., and Moroz, D. (2002). "Effects of modafinil on cognitive performance during 40 hours of sleep deprivation in a warm environment." Military Psychology **14**(1): 23-47.

> The study examined the effect of modafinil on cognitive performance during 40-h of sleep deprivation in a warm environment. Five men were assigned to the stimulant (3x100mg/24-h) and a placebo trial on consecutive weeks, with a 5-day intervening "wash-out" period. Findings reveal that 1) despite significant increases in core body temperature, cognitive performance was largely unaffected by the warm environment per se, 2) sleep loss induced a general reduction in cognitive performance that was largely but not completely eliminated by modafinil, and 3) participants were able to accurately self-monitor their own cognitive capabilities during both the placebo ad modafinil trials.

[9] Belenky, G. L. (1997). "Sleep, sleep deprivation, and human performance in continuous operations." Retrieved November 2, 2006, from http://www.usafa.af.mil/jscope/JSCOPE97/Belenky97/Belenky97.htm.

> Sleep was studied through actigraphy during simulated armored and mechanized infantry operations at the National Training Center (NTC) in the high desert of Southern California. These operations involve battalion sized task forces, and consist of 14 days of force-on-force and live-fire exercises. Sleep at the NTC was brief and fragmented. Notable in this study were the clear correlations between sleep and rank, and between sleep and echelon of command and control. Whereas the personnel at the squad and crew level averaged between 7-8 hours of sleep each night, those at battalion and brigade level averaged little more than 4 hours of sleep each night. From the perspective of sleep and its effects on performance, it was found that personnel at lower echelons were more effective than personnel at higher echelons. Although the more junior personnel improved their performance over the course of the exercise, the more senior personnel was observed to be "droning" (an informal term used by the rangers which denotes the cognitive status where the personnel has difficulty in grasping their situation or acting on their own initiative).

[10] Belenky, G. L., Krueger, G. P., Balkin, T. J., Headley, D. B., and Solick, R. E. (1987). Effects of Continuous Operations (CONOPS) on Soldier and Unit Performance: Review of the Literature and Strategies for Sustaining the Soldier in CONOPS. Walter Reed Army Institute of Research, Division of Neuropsychiatry, WRAIR-BB-87-1, Washington, D.C.

> The paper includes two chapters. The first is a review of the literature on effects of sleep deprivation and requirements for sustained performance on the ability of soldiers to conduct CONOPS. The topics covered are: adaptation to restricted sleep, effects of fragmented sleep, sleep timing, importance of sleep stages, circadian rhythms, effects of age, wearing chemical protective clothing, the nature of optimum alertness. Also covered are short descriptions of soldier sustained performance studies from various military labs. The second chapter contains a detailed list of human factors principles and recommendations for sustaining soldiers' performance in CONOPS. It includes topics such as: training and preparation for CONOPS, sleep scheduling, recovery sleep concepts, work/rest scheduling, naps and sleep discipline, sleep-inducing drug for use in long range deployments, alertness sustaining drugs for use in CONOPS, lightening the soldier's load, nutrition, and physical fitness for military tasks.

[11] Bell, D. G., Ducharme, M. B., Drolet, E. J. G., and Boyne, S. J. (2005). Impact of a Field Operation in IPE MOPP4 and COLPRO on Sleep. Defence Research and Development Canada (DRDC) Toronto DNBCD, DRDC Toronto TR 2005-002.

> The report examined the effects on sleep posed by working in the two different environments that protect against chemical threats. Ten (7 male and 3 female) regular Canadian Forces personnel were divided into two groups to perform various command post (CP) duties for 24 hours while in a chemical threat scenario environment wearing individual protective ensemble (IPE MOPP 4) or in

a collective protective facility (COLPRO) wearing IPE MOPP 0. During the trials, sleep was monitored and recorded using actigraph technology. The results from the report showed that soldiers had significantly less sleep and that there were awake more often during the night in the MOPP 4 ensemble. The study concluded that if the soldiers continued their duties in MOPP 4 over 48 hours, sleep deprivation would be considered serious and would lead to an exponential decrement in cognitive and physical performance.

[12] Belland, K. M. and Bissell, C. A. (1994). "A subjective study of fatigue during Navy flight operations over southern Iraq: Operation Southern Watch." Aviat Space Environ Med **65**(6): 557-561.

The study evaluates fatigue and responses to fatigue in naval aviation aircrew personnel aboard Carrier Air Wing FIVE (CVW-5) aboard U.S.S. INDEPENDENCE, during sustained and continuous operations at the onset of Operation Southern Watch in 1992. Analysis was conducted on CVW-5 aircrew subjective fatigue reports (n=125) during and immediately after the 18th day of intensive carrier aviation operations enforcing the "No Fly Zone" over southern Iraq. The majority of pilots reported some form of fatigue. Results show that no sleep/ wake cycle was established during the operations, although mean sleep was 6-h prior to operations and reduced to 5.6-h during the operations. Finally, the conclusions of the survey provided indicators for monitoring fatigue during patrols of 5-6 hours.

[13] Blassingame, S. R. (2001). Analysis of self-reported sleep patterns in a sample of U.S. Navy submariners using non-parametric statistics. Operations Research, Naval Postgraduate School, Monterey, CA.

Purpose of the study is to gain insight into the sleeping habits of U.S. Navy submariners. Using data supplied by the Naval Submarine Medical Research Laboratory, the study evaluates what a sub-sample of this population think about their sleep habits and will determine 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. The statistical analysis showed that there are discernable differences in the quality and quantity of sleep onboard U.S. submarines. There is a positive correlation between the amount of sleep obtained and the desired amount of sleep to function at every operational condition. Of the four operational conditions evaluated, the ‘at sea’ condition is the most different from all other conditions. Submariners reported getting less sleep while ‘at sea’ than other conditions. Finally, there is a positive correlation between the amounts of sleep obtained (both total sleep and uninterrupted sleep) and the desired amounts of sleep needed to function in every operational condition leading to the inference that subjects who report needing more sleep do indeed get more sleep. 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.

[14] Bonnet, M. H. (1991). "The effect of varying prophylactic naps on performance, alertness and mood throughout a 52-hour continuous operation." Sleep **14**(4): 307-315.

> The current study reports the effect of 0-8-hr naps placed prior to two consecutive nights of total sleep deprivation. A total of 104 young adult male subjects were randomly assigned to one of four prophylactic nap conditions (0, 2, 4 or 8 hr). After a normal baseline night of sleep and a morning of baseline test performance, subjects returned to bed at 1200, 1600 or 1800 hr or not at all prior to a continuous operation that extended until each subject's normal bedtime on the third following night. All subjects who napped arose at 2000 hr, and all subjects maintained the same schedule of computer-administered performance tests throughout the sleep-loss period. Results indicated that performance and alertness in all nap conditions were improved in a dose-response fashion compared to a no-nap control throughout the first 24 hr of sleep loss. However, significant improvement in nap conditions compared to the no-nap condition was not seen in many variables during the second night of sleep loss. Whereas an 8-hr nap prior to an operation maintained performance at a high level for 24-30 hr, significant improvement in alertness and performance as compared to the no-nap control was also documented by shorter naps. Napping could not reverse the profound loss of alertness seen during the second night of sleep loss.

[15] Bonnet, M. H., Gomez, S., Wirth, O., and Arand, D. L. (1995). "The use of caffeine versus prophylactic naps in sustained performance." Sleep **18**(2): 97-104.

> Previous studies have shown that performance during sleep loss is improved by prophylactic naps as a function of varying nap length. Based on single-dose caffeine studies, a similar dose-response effect has been hypothesized on performance, alertness and mood during sleep loss. The present study compared the effects of repeated versus single-dose administration of caffeine and varying amounts of sleep taken prior to sleep loss on performance, mood and physiological measures during 2 nights and days of sleep loss. A total of 140 normal, young adult males participated at one of two study sites. Ninety-eight subjects at one site were randomly assigned to one of four nap conditions (0, 2, 4 or 8 hours) and 42 subjects at the second site were assigned to one of four caffeine conditions. After a normal baseline night of sleep and morning baseline tests of performance, mood and nap latency, subjects in the nap groups returned to bed at noon, 1600 hours, 1800 hours or not at all. Bedtimes were varied so that all naps ended at 2000 hours. Subjects in the caffeine groups received either a single 400-mg dose of caffeine at 0130 hours each night or repeated doses of 150 or 300 mg every 6 hours starting at 0130 hours on the 1st night of sleep loss. A placebo control group (no nap and placebo administered every 6 hours on the repeated caffeine schedule) was run at both sites. Results show that performance, mood and alertness are directly proportional to prophylactic nap length. Furthermore, an 8-h nap is superior in maintaining performance, mood and alertness to either single or repeated caffeine administration. In general, naps provided longer and less graded changes in performance, mood and alertness than did caffeine, which displayed peak effectiveness and loss of effect within about 6-h. Shorter prophylactic naps and small repetitive doses of caffeine, however, did

maintain performance, mood and alertness during sleep loss significantly better than no naps or large single doses of caffeine. Neither nap nor caffeine conditions could preserve performance, mood and alertness near baseline levels beyond 24 hours, after wich levels approached those of placebo.

[16] Bourgeois-Bougrine, S., Cabon, P., Gounella, C., Mollard, R., and Coblemetz, A. (2003). "Perceived Fatigue for Short- and Long-Haul Flights: A Survey of 739 Airline Pilots." Aviat Space Environ Med **74**(10): 1072-7.

The aim of this study was to clarify what fatigue means to pilots on short- and long-haul flights (SHF and LHF, respectively). Methods: Questionnaires were distributed to pilots through four airlines. Questions concerned the perceived causes of fatigue, its signs and symptoms in the reporting pilot and observed in others, as well as the strategies used to minimize its impact. Of 3,436 questionnaires distributed, 739 (21.5%) were returned. Results show that of LHF, fatigue was seen as mainly due to night flights (59%) and jet lag (45%). For SHF, fatigue was caused by prolonged duty periods (multi-segment flights over a sequence of 4 to 5 d) (53%) and successive early wake-ups (41%). Self-reported manifestations of fatigue in 60% of LHF pilots and 49% of SHF pilots included reduction in alertness and attention, and a lack of concentration. Signs observed in other crewmembers included an increase in response times and small mistakes (calculation, interpretation). When pilots were tired, all the flying tasks seemed to be more difficult than usual. In both LHF and SHF, rest and sleep management were the primary strategies used to cope with fatigue. Analysis showed that duty time is a major predictor of fatigue, but that it cannot be considered independently from the other contributory factors. For both LHF and SHF, pilots reported acute fatigue related to sleep deprivation, due mainly to work schedules: night flights, jet-lag, and successive early wake-ups. These causal factors could easily be assessed in investigation of accidents and incidents.

[17] Brictson, C. A. and Young, P. A. (1980). Measures of navy pilot workload, sleep and performance in stressful environments. Office of Naval Research (Code 441), Environmental Physiology Division, Arlington, VA.

The report focuses on pilot sleep, workload and performance data in two stressful environments, aboard the aircraft carrier USS KENNEDY during a seven-month deployment to the Mediterranean Sea, and during two Carrier landing Qualification (CQ) classes. Both conditions included day and night landings. The air-wing's operational tempo was typical for peacetime. The attack aviators worked 12-h days regardless of flight activity. Mean flight activity accounted for 57% of the normal work day. High workload periods depicted slight increase of daily sleep (to 8-h), and there was a tendency for pilots to take short naps during flying periods. About 38% of the pilots reported non-recuperative sleep during ship transit and high flight activity.

[18] Buguet, A. (1995). Sleep Recovery from Physical Exercise: A New Understanding of Brain Responses to Stress. The effect of prolonged military activities in man. Physiological and biochemical changes. Possible means of rapid recuperation - RTO-MP-042, Oslo, Norway, NATO RTO.

The effects of physical exercise on human sleep (exercise in temperate conditions, in the cold and in hot climates) are analyzed and compared to studies on sedentary sleep in extreme environments (tropical and polar climates), and on sleep in rats after stressful events (sleep deprivation). An attempt to interpret the stress-induced sleep changes is developed, involving a "central" response and a "general" stress response. These responses ("diachronic" or "synchronic") are also examined in relation to chronobiological mechanisms. In conclusion, when the brain can deal with the stressful situation, the diachronic increase in slow-wave sleep and/or REM sleep occurs. When this pathway is overloaded, the classical stress reaction occurs with diachronic and synchronic disruptions of sleep architecture.

[19] Caldwell, J. A. (1997). "Fatigue in the aviation environment: an overview of the causes and effects as well as recommended countermeasures." Aviat Space Environ Med **68**(10): 932-938.

Review of fatigue in aviation pilots, and the recovery gained by prophylactic naps.

[20] Caldwell, J. A. (2003). An overview of the utility of stimulants as a fatigue countermeasure for aviators. U.S. Air Force Laboratory, AFRL-HE-BR-TR-2003-0024, Brooks City-Base, TX.

Overview of aviator-oriented fatigue and information on stimulants.

[21] Caldwell, J. A. (2005). "Fatigue in aviation." Travel Medicine and Infectious Disease **3**: 85-96.

Overview of pilot fatigue issues, in the commercial and military operations. The issues discussed are the neurophysiological evidence of fatigue in flight operations, the effect of circadian rhythms, and the major factors that affect the development of fatigue. Large part is dedicated to possible solutions for countering fatigue in aviation (for example, napping, education regarding sleep and fatigue, optimization of work-rest schedules, etc.).

[22] Caldwell, J. A. and Caldwell, J. L. (2005). "Fatigue in military aviation: an overview of U.S. military-approved pharmacological countermeasures." Aviat Space Environ Med **76**(7 Suppl): C39-51.

Overview of compounds that have been authorized by the U.S. military to be used as fatigue pharmacological countermeasures. Various components of the U.S. military have authorized the use of specific compounds for this purpose. Hypnotics such as temazepam, zolpidem, or zaleplon can mitigate the fatigue associated with insufficient or disturbed sleep. Alertness-enhancing compounds such as caffeine, modafinil, or dextroamphetamine can temporarily bridge the gap between widely spaced sleep periods. Each of these medications has a role in sustaining the safety and effectiveness of military aircrews. The present paper provides a short overview of these compounds as well as factors to be considered before choosing one or more to help manage fatigue.

[23] Caldwell, J. A., Caldwell, J. L., Brown, D., and Smith, J. (2004). "Modafinil's effects on simulator performance and mood in pilots during 37 h without sleep." Aviat Space Environ Med **75**(9): 777-84.

The purpose of this study was to determine whether modafinil (100 mg after 17, 22, and 27 h without sleep) would attenuate the effects of fatigue on fighter-pilot mood and performance during 37 h of continuous wakefulness. A quasi-experimental, single-blind, counterbalanced design tested the effects of modafinil in 10 Air Force F-117 pilots. Results showed that modafinil attenuated flight performance decrements on six of eight simulator maneuvers. Overall, modafinil maintained flight accuracy within approximately 15–30% of baseline levels, whereas performance under the no-treatment/placebo condition declined by as much as 60–100%. Modafinil decreased self-ratings of depression and anger, while improving ratings of vigor, alertness, and confidence. Benefits were most noticeable after 24 to 32 h of continuous wakefulness. One potential drawback of modafinil was that, at least at the 100-mg dose level, the drug's effects were not subjectively salient. Since this may lead personnel to escalate the dose without flight surgeon approval, personnel should be cautioned regarding this particular drug characteristic. Although modafinil did not sustain performance at pre-deprivation levels, the present study suggests that modafinil should be considered for the military's armament of short-term fatigue countermeasures. Future research will evaluate whether 200-mg doses are more beneficial than the 100-mg doses used here.

[24] Caldwell, J. A., Caldwell, L. J., Brown, D., Smythe, N., Smith, J., Mylar, J., Mandichak, M., and Schroeder, C. (2003). The effects of 37 hours of continuous wakefulness on the physiological arousal, cognitive performance, self-reported mood, and simulator flight performance of F-117A pilots. Air Force Research Laboratory, AFRL-HE-BR-TR-2003-0086, Brooks City-Base, TX.

Ten qualified F-117 pilots of the 49th , Fighter Wing at Holloman Air Force Base, NM, were used to evaluate the impact of 37-h of continuous wakefulness. Wakefulness severely degraded two of the eight performance measures from MATB and two of the four from the ANAM mathematical processing task. Decrements were evident in CNS arousal, self-reported mood and alertness ratings, all related to increased sleepiness. Substantial decrements were clear in objective flight-performance data (pilots' basic abilities to precisely maintain target headings, altitudes, airspeeds, etc.). Most noticeable decrements occurred after 27 hours awake. Performance in sustained operations was found to be substantially affected by two primary factors: the amount of time elapsed since the last sleep period and the time of day according to the body's internal clock.

[25] Caldwell, J. A. and Gilreath, S. R. (2002). "A survey of aircrew fatigue in a sample of U.S. Army aviation personnel." Aviat Space Environ Med **73**: 472-480.

> 241 Army aviators and 120 Army enlisted crew members participated in the study to evaluate the significance of fatigue in Army aviation. Results show that aviators reported working on average more than 60-h per week (including commuting time). Most time at work is spent in duties other than flying (administrative, training, maintenance, or other). On an organizational level, the study findings suggest that problems may remain with regard to ensuring sleep quality in field/ deployment settings, and with regard to scheduling crews' flight program in ways that improve on-the-job alertness by maximizing off-duty sleep.

[26] Caldwell, J. A., Gilreath, S. R., Erickson, B. S., and Smythe, N. K. (2000). Is fatigue a problem in Army Aviation? The results of a survey of aviators and aircrews. U.S. Army Aeromedical Research Laboratory, USAARL Report No. 2001-03, Fort Rucker, AL.

> The study analyzes the responses on fatigue and sleep from 241 Army aviators and 120 Army enlisted crew members. The results indicate that inadequate sleep and/or insufficient sleep quality is adversely affecting on-the-job alertness. The requirements to work a variety of schedules and to travel/work away from home are likely contributing to less than optimal sleep quality; however, a number of personnel may be suffering from sleep deprivation due to intentional sleep restriction as well. The personnel surveyed in this study indicated they were sleeping less than 7 hours per night which is 1 hour less than the amount recommended. This insufficient sleep, combined with rotating schedules and other work demands, no doubt contributed to the perceptions of three-quarters of the present sample that fatigue is a widespread problem in the military aviation community. These results indicate the importance of continuing to stress fatigue-reduction strategies in training and operational environments.

[27] Caldwell, J. A., Jr. and LeDuc, P. A. (1998). "Gender influences on performance, mood and recovery sleep in fatigued aviators." Ergonomics **41**(12): 1757-70.

> The study examines responses of men and women aviators to sleep deprivation. Twelve UH-60 pilots were tested on flight performance and mood during 40-h periods of sustained wakefulness at a flight simulator. Baseline and recovery sleep also were examined. Gender produced no operationally-significant effects of flight performance or recovery sleep. Although mood tests showed that women felt less tense and more energetic than men, there were no interactions between sleep deprivation and gender on either flight performance or psychological mood.

[28] Caldwell, J. A. J., Jones, R. W., Caldwell, J. L., Colon, J., Pegues, A., Iverson, L., Roberts, K. A., Ramspott, S., Sprenger, W. D., and Gardner, S. J. (1997). The efficacy of hypnotic-induced prophylactic naps for the maintenance of alertness and performance in sustained operations. U.S. Army Aeromedical Research Laboratory, USAARL Report No. 97-10, Fort Rucker, AL.

> The double-blind investigation examined the efficacy of prophylactic naps induced with zolpidem tartrate, in comparison to placebo naps and a forced-rest

period, for sustaining the alertness of 18 Army aviators or flight students. Each subject received all three treatment interventions from 2100 to 2300 (13th-15th hour of sustained operations) on the evening prior to a night of sleep loss. Testing was conducted from 0100 until 2200 (17th-38th hour of sustained operations) the next day. Results indicated prophylactic naps were beneficial in terms of sustaining mood, alertness, and performance throughout the final 24 hours of 38-hour periods of sustained operations. Self-ratings of vigor, alertness, energy, talkativeness, fatigue, irritability, and sleepiness all were improved by strategic napping in comparison to forced rest. Physiological indices demonstrated subjects were better able to remain awake after napping than after rest only. Also, there were electroencephalographic indications that central nervous system arousal was maintained more effectively by napping than by forced rest. Alertness decrements due to sleep loss were most severe between 0400 and 1000. Cognitive performance often, but not always, was impaired by sleep deprivation. Although subjects seemed to perform fuel management, desktop flight simulation, and auditory monitoring about as well when totally sleep deprived as after naps, they were better able to monitor systems, respond to warning lights, manage radios, track targets, and perform mental calculation after napping than after rest only, especially between 0700 and 1100.

[29] Caldwell, J. L. (2002). Efficacy of napping strategies to counter the effects of sleep deprivation. Sleep/ Wakefuleness Management in Continuous/ Sustained Operations - RTO Lecture Series 223. Neuilly-sur-Seine, France, NATO RTO. **RTO-EN-016 AC/323(HFM-064)TP/39**.

The study addresses a) whether a 2-h nap placed late in the evening would affect performance, mood and sleepiness during a continuous operations scenario, and b) whether zolpidem tartrate could be effectively used to promote naps. Eighteen male aviators participated in the 9-day test period. Results indicated that there was faster sleep onset, greater minutes of sleep, less stage 1 sleep, and more stage 4 sleep after zolpidem than placebo. Evaluation of two types of 2-hour prophylactic naps (one induced with 10-mg zolpidem and the other a natural, or placebo, nap) during the final 23 hours of a 38-hour period of continuous wakefulness supported previous findings, which indicated both naps were superior to a forced-rest condition in terms of sustaining alertness. Comparisons between the zolpidem and placebo naps indicated the zolpidem nap was superior in several instances. Zolpidem's rapid onset of action can be of significant benefit in situations where there is only a brief period available for sleep or naps are possible, and the timing is less than optimal.

[30] Caldwell, J. L., Caldwell, J. A. J., Colon, J., Ruyak, P. S., Ramspott, S., Sprenger, W. D., and Jones, R. W. (1998). Recover of sleep, performance, and mood following 38 hours of sleep deprivation using naps as a countermeasure. U.S. Army Aeromedical Research Laboratory, USAARL Report No. 98-37.

The objective of the study is to determine: a) if a soldier recovers from 38-h of continuous work more quickly when a 2-h nap is taken during the 38-h then when only a rest period is given, and b) the impact of using a medication to promote the nap in terms of recovery. Results indicate that 10-h of sleep following 38-h of continuous wakefulness, with the addition of a 2-h nap, is generally adequate to recover from the effects of sleep deprivation, with the exception of a possible decrement in morning alertness following wake-up from recovery sleep. Although baseline performance generally was not different from recovery performance, alertness and mood were affected up to 2-h post-awakening. The addition of zolpidem to promote sleep during the nap produced better performance and alertness than placebo, although this difference was not overwhelming.

[31] Caldwell, J. L., Caldwell, J. A. J., and Roberts, K. A. (2002). A comparison between the countermeasures modafinil and napping for maintaining performance and alertness using a quasi-experimental analysis. U.S. Army Aeromedical Research Laboratory, USAARL Report No. 2002-14, Fort Rucker, AL.

The study assess the efficacy of modafinil to a 2-hour nap for sustaining cognitive skill and psychological mood in helicopter pilots (n=18 for nap study and n=6 for modafinil study) who have been sleep deprived. The two countermeasures were found to be effective but not comparable. Modafinil appeared to be superior to napping in maintaining alertness, attenuating mood changes, reaction time, and errors of omission.

[32] Caldwell, J. L., Gilreath, S. R., and Norman, D. N. (1999). A survey of work and sleep hours of U.S. Army Aviation Personnel. U.S. Army Aeromedical Research Laboratory, USAARL Report No. 99-16, Fort Rucker, AL.

The survey determines when Army aviation personnel work and sleep while on reverse cycle. From a sample of 157 aviation personnel from 3 Army posts, results show that the majority of aviation personnel had experience working night shift/ reverse cycle; however, over one third had not dealt with this shift for more than 3 years. Usually the night shift occurred from early in the afternoon to early in the morning. Most responders indicated they were able to sleep after a night shift for at least 7-h, but many of them indicated they did not feel they received adequate daytime sleep most or some of the time. Although many aviators reported returning home by 04:00, there is a large percentage who indicated they did not return home until after 08:00, making it difficult to obtain adequate sleep.

[33] Cauter, E. V. and Buxton, O. M. (2000). Phase-shifting effects of light and activity on the Human Circadian Clock. University of Chicago, Department of Medicine, AFRL-SR-BL-TR-00, Chicago, IL.

The review describes a number of studies conducted at the University of Chicago that examined jet lag and sleep loss conditions relevant to Air Force operations. First, a series of studies examined the photic and non-photic means by which the timing of the human circadian system can be changed. These protocols were typically of 304 days duration involving collection of 24-h profiles of physiological parameters under "constant routine" conditions to determine the phase-shifting effects of exercise and dark/ sleep on hormonal markers of circadian phase. Second, the effects of partial sleep loss on metabolic, endocrine, cognitive, cardiovascular, and immune function, neurobehavioral performance, and subjective sleepiness and mood have been examined. These protocols involved 16-day studies with one-week periods of sleep restriction to 4-h/night and sleep extension to 12-h/night. The results from all studies indicate that: 1) periods of either exercise or dark/sleep can change circadian phase, which has potential practical benefits for conditions of jet lag and night work, and 2) sleep loss has a profound deleterious impact on human health and performance than can be improved by sleep extension.

[34] Chaiken, S., Barnes, C., Harville, D., Miller, J., Dalrymple, M., Tessier, P., Fischer, J., and Welch, C. (2004). Do teams adapt to fatigue in a synthetic C2 task? United States Air Force Research Laboratory, Human Effectiveness Directorate, AFRL-HE-BR-TR-2004-0041, Brooks City-Base, TX.

The study investigates how team performance degrades with sustained operations on a PC-based air battle management synthetic task. Participants were ten, 3-person teams as part of USAF officers awaiting Air Battle Management Training. Teams of ISR, Strike, and Sweep battle managers conducted 8 one-hour missions along with performance assessment batteries. Results showed that fatigue degraded participants' cognitive performance and one dimension of mission outcome (number of enemy kills) but not others (friendly losses to fuel outs and hostile actions). General activity declined for the team roles (number of orders issued, information seeking). No evidence of adaptation to fatigue (such as strategy change) was found. Finally, while roles recognized the value of offloading work onto the lighter role, this tendency did not significantly increase with fatigue.

[35] Chidester, T. R. (1986). Mood, sleep, and fatigue effects in flight operations. Proceedings of theTenth Symposium, Psychology in the Department of Defense, Technical Report No. 86-1. G. E. Lee. Colorado Springs, CO, USAFA**:** 289-293.

A survey of airline pilots (463 short-haul and 57 transmeridian) was undertaken to determine normative patterns in mood and sleep during short-haul (involving multiple, relatively short flights segments often crossing 1 or 2 time zones) and transmeridian flights (usually involve only one flight segment per day and cross no less than 3 time zones). The results revealed mood and sleep disturbances (reduced sleep quality and amount) in both short-haul and transmeridian operations, but the effects are more severe on the latter flights.

[36] Co, E. L., Gregory, K. B., Johnson, J. M., and Rosekind, M. R. (1999). Crew factors in flight operations XI: A survey of fatigue factors in regional airline operations. NASA Ames Research Center, NASA/TM-1999-208799, Moffett Field, CA.

This report is the eleventh in a series on the physiological effects of flight operations on flight crews. A 119-question survey was completed by 1,424 flight crewmembers from 26 regional carriers to identify factors contributing to fatigue in regional airline operations. Eighty-nine percent of crewmembers identified fatigue as a moderate or serious concern with 88% reporting that it was a common occurrence and 92% reporting that, when it occurs, fatigue represents a moderate or serious safety issue. However, 86% reported they received no company training addressing fatigue issues. Identified fatigue factors included multiple flight segments, scheduling considerations, varying regulations, and others. The two most commonly cited fatigue factors regarded flying multiple (more than four) segments. Scheduling factors accounted for nine of the ten most common recommendations to reduce fatigue in regional operations. Differing requirements among regulations were cited as contributing to fatigue. Other identified factors were the flight deck environment, automation, and diet. The data suggested specific recommendations, including education of industry personnel about fatigue issues and examination of scheduling practices. Education plays a critical role in any effort to address fatigue. Analyzing scheduling practices and identifying potential improvements may result in reduced fatigue as well as other benefits to operations.

[37] Comperatore, C. A., Bloch, C., and Ferry, C. (1999). Incidence of sleep loss and wakefulness degradation on a U.S. Coast Guard Cutter under Exemplar crewing limits. U.S. Coast Guard Research and Development Center, CG-D-14-99, Groton, CT.

The goals of the USCG Exemplar project includes the exploration of the potential use of reduced crew complements aboard high endurance cutters. One major concern is that crew reductions may exacerbate crew fatigue and ultimately compromise safety. The central objective of this study was to determine whether crew members are experiencing unacceptable fatigu`e levels while sailing under Exemplar crew reductions. This study was conducted aboard the CG Cutter MUNRO (WHEC-378 foot) during a patrol from Tokyo, Japan to Pearl Harbor, Hawaii. Daily evaluations of alertness (maintenance of wakefulness) and of the stability of the sleep/wake cycle (variability of sleep duration and timing) were used to characterize fatigue levels throughout 30 consecutive days on patrol. Fourteen crew members participated in wakefulness maintenance tests consisting of the observation of the latency to sleep onset (as indicated by brain wave activity) while volunteers attempted to maintain wakefulness. Nine out of 14 participants failed to maintain wakefulness in 57 to 100 percent of the tests. Forty-three volunteers participated in daily sleep evaluations by wearing wrist-worn activity monitors 24 hours per day. Activity monitor data were used to document daily sleep onset times, wake-up times, and the stability of the sleep/wake cycle throughout the 30-day evaluation. Over sixty percent of all scored sleep profiles exhibited severe disruptions in sleep patterns. Correlation analysis confirmed that participants experiencing frequent disruptions of the sleep/wake cycle also suffered reductions of sleep below six hours and a high incidence of failure to maintain wakefulness above six minutes, signifying reduced alertness. Watch schedules requiring frequent rotations from daytime to nighttime (0000-0400) and early morning (0400-0800) duty hours contributed to the consistent disruption of sleep/wake cycles. The combination of current watch schedules, reduced personnel, and high operational tempo are expected to exacerbate the fatigue symptoms documented in this patrol. To minimize sleep/wake cycle disruptions, it is recommended that the frequency of rotation from daytime to night and early morning duty hours be reduced.

[38] Comperatore, C. A., Kingsley, L., Kirby, A., and Rivera, P. K. (2001). Management of endurance risk factors: A guide for deep draft vessels. U.S. Coast Guard Research and Development Center, CG-D-07-01, Groton, CT.

> Crew members aboard deep draft vessels traditionally endure harsh working conditions, extreme temperatures, long work hours, frequent separation from loved ones, and fatigue. While a ship's endurance is determined by how long it can support operations at sea without replenishing supplies or requiring in-port maintenance, its crew members' endurance is determined by their ability to cope with job-related physiological, psychological, and environmental challenges. Uncontrolled stress factors reduce mental and physical endurance and demand more concentration on the immediate task at hand. Crew members forfeit advanced planning and the ability to anticipate safety risks. Safety deteriorates as a crew becomes more reactive. Controlling these decrements in performance is critical to productivity and safety. This Guide is designed as a resource for captains, department heads, and officers, as well as company safety and operations managers in the shipping industry to control crew endurance risk factors such as stress, fatigue, sleep deprivation, and problems resulting from working and living on deep draft vessels. Section I introduces the concept of crew endurance management. Section II provides specific guidance on how to recognize endurance risk factors and the detrimental effects of psychological, physiological, and environmental stress factors. Specific recommendations are provided as to how to effectively address crew endurance risk factors. Section III provides specific guidelines on how to assess crew endurance and implement improvements in crew management practices. The principles provided in this Guide have been tested in a variety of maritime environments, including marine shipping companies, towing vessel companies, U.S. Coast Guard cutters, small boat stations, and aviation units.

[39] Comperatore, C. A., Kirby, A., Bloch, C., and Ferry, C. (1999). Alertness Degradation and Circadian Disruption on a U.S. Coast Guard Cutter Under Paragon Crewing Limits. U.S. Coast Guard Research and Development Center, CG-D-23-99, Groton, CT.

> Crew alertness and the incidence of sleep/wake cycle disruptions were evaluated aboard DEPENDABLE, a WMEC, throughout 32 consecutive days underway. This study was conducted during the implementation of crew reductions prescribed by the Paragon project. Thirty male crew members volunteered to participate in the study. Wrist activity monitors (WAMs) were used to document sleep/wake cycles and electroencephalography (EEG) techniques were used to measure alertness. Thirty participants wore WAMs throughout the study period, while a subset of 14 volunteers participated in short duration EEG alertness tests every three to five days. Alertness tests were administered within three hours of wakefulness from daily sleep. Participants were allowed to follow their daily routine prior to reporting for the wakefulness tests. Unremarkable weather conditions and low operational tempo characterized this patrol. However, analysis of sleep/wake cycles and EEG alertness tests revealed a 59 percent incidence of sleep/wake cycle disruption associated with high failure rates in the EEG alertness

tests. Twelve out of the 14 EEG participants failed to maintain wakefulness in 50 to l00 percent of the tests. Participants working under non-rotating watch schedules (e.g., 0400-0800) exhibited consistent patterns of sleep and wake-up times with sleep duration rarely dipping below six hours. In contrast, participants exposed to frequent watch rotations showed disrupted sleep associated with the 0000-0400 and 0400-0800 watch schedule. Recommendations include the implementation of: a) a crew endurance education program to optimize the quality of crew rest; b) watch schedules that minimize sleep/wake cycle disruptions; c) the development of a system to reduce crew members' frequent rotation into the 0000-0400 or 0400-0800 watch schedules.

[40] Comperatore, C. A. and Rivera, P. K. (2003). Crew endurance management practices: A guide for maritime operations. U.S. Coast Guard Research and Development Center, CG-D-01-03, Groton, CT.

This guide presents a formal program of practices (the Crew Endurance Management System) for controlling risk factors that affect crewmember performance and shipboard safety in the commercial maritime industry. The CEMS program is overviewed; a real-world example is provided; techniques for managing crewmember energy and performance levels are provided; operational risk factors affecting crewmember energy and performance levels are addressed; procedures for implementing a CEMS program are described; and supplementary materials are provided.

[41] DeJohn, C. A. and Reams, G. G. (1992). An analysis of a sustained flight operation training mission in navy attack aircraft. Naval Aerospace Medical Research Laboratory, NAMRL-1370, Pensacola, FL.

The study evaluated pre- and post-mission performance decrements of three squadrons from Carrier Air Wing 15 (CVW 15) onboard USS CARL VINSON. The pilots (n=20) were involved in a practice, long range, over-water, strike mission while the ship was underway (transiting). Carrier landing scores significantly increased compared to previous 2 months average, possibly due to learning effect; cognitive and vision performance remained stable. The findings suggest that participants were well rested, and that the scenario used was not fatiguing enough.

[42] DeJohn, C. A., Shappell, S. A., and Neri, D. F. (1992). Effects of dextromethamphetamine on subjective fatigue. Naval Aerospace Medical Research Laboratory, NAMRL-1376, Pensacola, FL.

The study reports the ability of the central nervous system (CNS) stimulant d-methamphetamine to alleviate the effects of SUSOPS on subjective fatigue. The study was conducted through questionnaires administration to 25 male U.S. Marines. The simulated SUSOP consisted of a 9-h planning session followed by 4-h rest and a 14-h mission. After a 6h sleep the pattern was repeated. At 4.5-h into the second iteration (mission) 13 participants were administered the stimulant whereas 12 participants received a placebo. Results showed that the administration of d-methamphetamine significantly reduced reported fatigue scores on the Addiction Research Center Inventory (ARCI) ($p<0.05$), Mood Questionnaire (MQ) ($p<0.05$), and sleepiness through Stanford Sleepiness Scale (SSS) ($p<0.05$).

[43] Doheney, S. W. (2004). Sleep logistics as a force multiplier: An analysis of reported fatigue factors from Southwest Asia Warfighters. Operations Research, Naval Postgraduate School, Monterey, CA, 269.

The purpose of the study is to analyze data related to sleep patterns of warfighters deployed to the Southwest Asia (SWA) Area of Operation. Subjective survey data was collected from warfighters operating in Iraq and Kuwait from 25 August - 15 October 2003 (n = 273). Participants were asked about unit-level sleep planning, sleep/wake patterns, and lifestyle factors. Using the survey results, insight was gained into the four primary research questions: 1) Is sleep deprivation a significant problem for forces in the SWA region; 2) Do current sleep logistics support a unit's ability to accomplish assigned missions; 3) Are there differences in sleep patterns between subset populations; and 4) Does the current survey method support the research objectives? To address these questions, analysis techniques such as principal components analysis, factor analysis, and parametric and nonparametric hypothesis testing were used. The reliability of the subjective survey results was tested by comparing self-reported survey data with actigraphy data corresponding to the same time period (n = 34 paired observations). This thesis also provides insight regarding the use of sleep logistics as a force multiplier during continuous/sustained operations by discussing known fatigue countermeasures and their role in improving individual and unit performance effectiveness.

[44] Driskell, J. E. and Mullen, B. (2005). "The efficacy of naps as a fatigue countermeasure: a meta-analytic integration." Hum Factors **47**(2): 360-77.

Modern requirements for extended operations in aviation, transportation, the military, and industry have led to extensive research on countermeasures to mitigate the adverse effects of fatigue. The goals of this research were to (a) summarize and integrate existing research on naps as a fatigue countermeasure using meta-analysis, (b) identify the strength and significance of the effects of naps on performance and feelings of fatigue, and (c) identify factors that may moderate the effects of napping as a fatigue countermeasure. The results of these analyses can be used to predict nap efficacy as a function of length of the nap and the postnap interval. The results of these analyses also suggest an approach to work design that takes into account the optimal effects of naps as a fatigue countermeasure. Actual or potential applications of this research include the development of optimal work schedules to minimize fatigue and increase safety.

[45] Evans, S. M., Mackie, R. R., and Wylie, C. D. (1991). Fatigue effects on human performance in combat: a literature review. U.S. Army Research Institute for the Behavioral and Social Sciences, ARI Research Note 91-90, Alexandria, VA.

The report is a literature review on the effects of fatigue and related stressors on the performance of military personnel engaged in diverse military tasks. Both mental and physical fatigue are considered. More than 500 articles, reports, and books are reviewed. The report divides the gathered material in three sections according to the relevance to the study's objectives. The first section contains full synopses on 40 studies, the 2nd section abbreviated synopses on 72 studies, and the 3rd section contains full citations on over 500 articles, reports, and books.

[46] Ferrer, C. F., Jr., Bisson, R. U., and French, J. (1995). "Circadian rhythm desynchronosis in military deployments: a review of current strategies." Aviat Space Environ Med **66**(6): 571-8.

The study reviews the research on circadian effects on the operational theater. There is a brief discussion of about circadian physiology, the possible relation to morbidity and mortality, and sleep hygiene in aviation. The factors reviewed are napping, exercise, diet, light therapy effect on the entrainment of circadian rhythms, and deployment strategies. Detail is given in the use of medication use of the USAF (sedatives, and stimulants).

[47] Foo, S. C., How, J., Siew, M. G., Wong, T. M., Vijayan, A., and Kanapathy, R. (1994). "Effects of sleep deprivation on naval seamen: II. Short recovery sleep on performance." Ann Acad Med Singapore **23**(5): 676-9.

Twenty male naval volunteers, aged 18 to 20 years, with 12 to 14 years of education, underwent a total sleep deprivation experiment on board a Republic of Singapore Navy landing ship in the South China Sea for a period of 42-102 hours. The sleep group comprised eight volunteers who dropped out at the 44th-46th h of the experiment and were randomly assigned to a 2 or 4 h sleep regime. The rest served as sleep-deprived controls. Neurobehavioural performance tests, profile of mood state and the Stanford Sleepiness Scale were applied 6-hourly starting from 6.00 am on the first experimental day. No thresholds were observed in the performance of tests related to manual tasks and subjective feeling, including naval tasks, mood and sleepiness scale during the sleep deprivation experiment. However, thresholds were observed in the performance of tests requiring cognitive and perceptive skills, including the grooved peg board, trail making, sea-shore rhythm, addition, digit span, digit symbol, flicker fusion and dynamometer tests. Performances in these tests were observed to deteriorate only after approximately 30 h of sleep deprivation. The Z score for the non-threshold tests (Z-N) deteriorated from -0.01 at the start of the experiment to 1.25 at the 42nd h of the experiment just before the imposed sleep and improved to 0.81 at the 48th h of the experiment just after the imposed sleep; and the Z score for the threshold tests (Z-T) varied from -0.07 at the start to 0.49 just before sleep (at the 42nd h) and to continuously deteriorate to 0.83 just after sleep (at the 48th h). Even though monotonous variations in performances for the Z scores were observed when the length of sleep was increased from 2 to 4 h, only performance of the 4-h sleep group was significantly different from the control in statistical tests. Results from the study suggest that performance tasks requiring cognitive and perceptual skills may not be benefited by sleep of 4-h or less. However, the rating of subjective feeling and the performance of work involving routine manual tasks can be improved after a 4-h sleep.

[48] French, J., Bisson, R. U., Neville, K. J., Mitcha, J. L., and Storm, W. F. (1994). "Crew fatigue during simulated, long duration B-1B bombers missions." Aviat Space Environ Med **65**(5, suppl.): A1-6.

> The study evaluates crew fatigue associated with successive and unaugmented 35-h missions in B-1B simulators. Data were obtained from 32 operationally qualified crewmembers. All crewmembers completed three consecutive, long duration missions, each preceded by 33 to 35-h of crew rest. Oral temperature, salivary melatonin and cortisol, as well as actigraph and subjective measures, were collected during all missions. Temperature and melatonin data indicate that crews maintained their local home base circadian cycles. Elevated cortisol and subjective fatigue during the first mission indicate that it was the most difficult of the three. Furthermore, quality and duration of sleep were lowest during the first mission. These findings emphasize the need for realistic training in long duration fatigue management to improve the safety and effectiveness of the first and subsequent missions.

[49] Hardaway, C. A. and Gregory, K. B. (2005). "Fatigue and sleep debt in an operational Navy squadron." The International Journal of Aviation Psychology **15**(2): 157-171.

> The amount of fatigue experienced by the aviators in an operational EP-3 squadron was quantified before and after interventions were made to promote crew rest. Surveys were completed for 10 days by 2 separate flight crews transitioning to a Southwest Asia detachment site from Whidbey Island Naval Air Station, Washington. The second crew (Crew B) underwent fatigue countermeasures training several days prior to departure and were provided with 1 additional layover day between the second and third day of transit. The additional layover period was provided in an effort to maximize crew rest prior to a difficult night transit 3 days into the journey. The surveys quantified: self-reported sleep quantity (A:6.19-h, B:6.6-h), sleep quality, sleep debt, and fatigue ratings during the 3 phases of flight: takeoff to top of climb, top of climb to top of descent, and top of descent to landing. Baseline data were collected from the first crew (Crew A) and were then compared to that of the second crew (Crew B). Crew A self reported greater fatigue, a larger sleep debt, and decreased sleep quality compared to Crew B. Both crews demonstrated low sleep quality ratings on the second day of the transit as well as high fatigue ratings after the third leg of the transit. Crew B received more total sleep prior to the third leg of the transit due to the additional layover day. This additional rest period resulted in decreased fatigue ratings for Crew B. Sleep quality tended to be lower on the nights preceding a scheduled flight and higher on days off. Providing additional layover time and fatigue countermeasures training resulted in decreased fatigue, increased sleep quantity, and improved sleep quality.

[50] Harville, D., Barnes, C., and Elliott, L. (2004). Team communication and performance during sustained command and control operations: preliminary results. Air Force Research Laboratory, AFRL-HE-BR-TR-2004-0018, Brooks City-Base, TX.

> Ten 3-person teams of USAF officers were used to evaluate the effect of fatigue on C4ISR communication and performance in complex time-critical targeting SUSOPS scenarios. Fatigue during night scenarios impacted communications, the requests for information on assets, and the strategy regarding information on the movement of assets or the sequencing of actions among team members.

[51] Haslam, D. R. (1985). "Sleep deprivation and naps." Behavior Research Methods, Instruments, and Computers **17**(1): 46-54.

> The study examines the effect of short duration sleep after a long wakefulness in two experiments. The first involves 10 infantrymen with 2 h of sleep following 90 h of wakefulness. The participants were ignorant of the period of wakefulness and of the fact that they would be allowed to sleep after the wakefulness period, until a few hours before the nap. After 3 nights without sleep, cognitive performance decreased to 55% of the control values. During a test session before the 2-h nap, performance reached 85%, which is indicative of the effect of incentive (the subjects knew that they would be allowed a nap). In the 2nd experiment two groups of six infantrymen participated in a 5-day trial; one group received a 4-h uninterrupted sleep whereas the other received four 1-h naps. No significant differences were evident between the two groups.

[52] Horn, W. G., Thomas, T. L., Marino, K., and Hooper, T. I. (2003). "Health experience of 122 submarine crewmembers during a 101-day submergence." Aviat Space Environ Med **74**(8): 858-62.

> The study examined patterns of minor medical problems, and self-treatment among the crew of one submarine over a period of continued submergence for 101 days. Study data were obtained from three self-administered serial surveys of 122 medically screened U.S. Navy personnel onboard a submerged nuclear-powered submarine at the beginning, middle, and end of the study. Results showed that during the first half of the study, 82% had medical complaints, most commonly runny nose, difficulty sleeping, and backache. In the second half, 77% listed complaints, most commonly difficulty sleeping. Despite readily available medical care, self-medication for minor unreported health problems was common, with use of products such as non-steroidal anti-inflammatory drugs, multi-vitamins, health supplements, topical preparations, and antihistamine/decongestants.

[53] Horne, J. A. and Reyner, L. A. (1996). "Countering driver sleepiness: Effects of napping, caffeine, and placebo." Psychophysiology **33**: 306-309.

> The study addresses the efficacy of countermeasures on drivers' sleepiness. The study examines a shorter than 15-min nap, 150-mg of caffeine in coffee, and a coffee placebo, each given randomly across test sessions to 10 sleepy subjects during a 30-min rest period between two 1-h monotonous early afternoon drives in a car simulator. Caffeine and nap significantly reduced driving impairments,

subjective sleepiness, and EEG activity indicating drowsiness. Blink rate was unaffected. Sleep during naps varied, whereas caffeine produced more consistent effects. Subjects acknowledged sleepiness when the EEG indicated drowsiness, and driving impairments were preceded by self-knowledge of sleepiness. Rest instead of a nap proved ineffective.

[54] How, J. M., Foo, S. C., Low, E., Wong, T. M., Vijayan, A., Siew, M. G., and Kanapathy, R. (1994). "Effects of sleep deprivation on performance of Naval seamen: I. Total sleep deprivation on performance." Ann Acad Med Singapore **23**(5): 669-75.

In the study, a homogeneous group of 20 seamen under total sleep deprivation was rated every 6 hours with the Stanford Sleepiness Scale (SSS), Profile of Mood States (POMS) and a battery of performance tests. With the exception of the trail making test and naval tasks, the test performance was observed to correlate significantly ($P < 0.05$) with the SSS. A higher sleepiness score was associated with a poorer performance in test scores. On the time trends of sleep deprivation on the performance tests measured, a dip in performance was observed in all the tests at 42 hours of sleep deprivation and continuous deterioration of performance was observed after 72 hours of sleep deprivation. The cognitive, vigilance, mood and sleepiness tests were substantially affected by sleep deprivation. Greater effect was observed in tests that involved cognition, speed and precision and smaller effect was observed in routine tasks that involved gross manual movement. The decrease in performance observed at 42 hours of sleep deprivation was 5.9 standard deviation from initial values for SSS; 3.9 for sea-shore rhythm, 3.0 for grooved peg board; 2.6 for dynamometer; 2.4 for mood; 1.8 for digit span; 1.6 for trail making and digit symbol; 1.0 for naval tasks and addition; and 0.9 for flicker fusion. All differences in test scores between the beginning of the test and at 42 hours of sleep deprivation were significant ($P<0.05$). The recovery in performance observed between 48 and 66 hours of sleep deprivation suggests that the military personnel may be able to perform their tasks for up to three days without sleep. After 72 hours of sleep deprivation, the continuous deterioration observed suggests that the performance of the military personnel would become ineffective thereafter.

[55] Huffman, A. H., Adler, A. B., Calhoun, M. E., and Castro, C. A. (2001). Measuring sleep and work demands in U.S. Army Senior Leaders. U.S. Army Medical Research Unit - Europe.

As part of a larger study investigating the workload of Senior Leaders in the U.S. Army, Europe, the sleep characteristics of key decision- makers were studied. The goal was to assess leaders' amount of sleep and relate their sleep habits to the demands of their actual work environment. Senior officers (N=21) in the United States Army completed an initial survey about their work habits, stressors, health, and family commitments. Throughout the study, participants wore and actigraph-monitoring device that measured activity and completed an Activity Survey every 2 weeks. Mean night sleep during weekdays was found to be 7.3-h. Mean reported working day lasted 12.2-h and was negatively correlated to obtained sleep amount ($r=-0.504$; $p<0.01$). Overall, results showed that higher

operational demands and stress were associated with reduced sleep time. Thus, it appears that the nature of the work environment is likely to affect the sleep habits of senior officers. This relationship needs to be better understood in terms of its possible impact on decision making and well-being given that leaders in any organization need to be able to maximize their performance and well-being during periods of high workload and work stress.

[56] Kamimori, G. H., Johnson, D. E., Thorne, D., and Belenky, G. L. (2005). "Multiple caffeine doses maintain vigilance during early morning operations." Aviat Space Environ Med **76**(11): 1046-50.

The goal of this study was to determine the optimal dose of caffeine for sustaining performance during sleep loss with administration of multiple doses. Methods: There were 48 subjects (28 men, 20 women) who were randomly assigned to 1 of 4 groups (placebo, 50, 100, or 200 mg caffeine). After an overnight 8-h sleep period, subjects were required to remain awake for the ensuing 29 h. Control data were collected until 03:00 (Day 3), followed by three 2-h test blocks. At 03:00, 05:00, and 07:00 subjects chewed two sticks of gum (Stay Alert chewing gum) containing caffeine or placebo. Six 10-min sessions on a version of the Psychomotor Vigilance Test (PVT) were completed during each 2-h test block. The Stanford Sleepiness Scale (SSS) was administered after each PVT. Lapses on the PVT were categorized as response times greater than 1, 3, or 5 s. Lapses in all categories significantly increased in the placebo group. Caffeine significantly reduced the number of lapses in a dose-related manner; and performance was maintained at baseline levels for the entire sleep loss period with multiple doses of 200 mg caffeine. There was a significant main effect for session on the SSS, the score increasing over time, but no significant differences between groups. Discussion: These results indicate that a bi-hourly administration of 200 mg of caffeine maintains vigilance performance across a single night without sleep.

[57] Kavanagh, J. (2005). Stress and Performance, a Review of the Literature and its Applicability to the Military. RAND, National Security Research Division, TR-192.

The report reviews the literature and empirical studies conducted on the relationships among stressors, stress, and performance in a variety of contexts, with a specific focus on stress in a military context. The literature review examines relevant studies in the psychological field and highlights those most relevant to military operations and training.

[58] Kelly, T., Grill, J. T., Hunt, P. D., and Neri, D. F. (1996). Submarines and 18-hour shift work schedules. Naval Health Research Center, 96-2, San Diego, CA.

The study evaluated the forced circadian desynchrony on crew members living onboard a submarine. The schedule was typical for submarines (6-on/ 12-off leading to 18-hour day). Sleep patterns and circadian rhythms were assessed through salivary melatonin, sleep logs, and actigraphs. Performance was evaluated through a performance assessment battery (PAB). Results from PAB, sleep logs, and actigraphy show that the crew appeared to get sufficient sleep (approximately 7-h). On average sleep occurred in more than one episode per day (on average 9.5 sleep episodes per week). Night sleep episodes decrease after the first part of the voyage, which is evidence of circadian shift. There was no resulting accumulated effect of PAB scores; the crew seemed to maintain acceptable performance levels on the 18-hour day work schedule.

[59] Kenagy, D. N., Bird, C. T., Webber, C. M., and Fischer, J. (2004). "Dextroamphetamine use during B-2 combat missions." Aviat Space Environ Med **75**(5): 381-6.

During Operation Iraqi Freedom, pilots flew the B-2 bomber to targets in Iraq from one of two airfields. Sortie durations were long (16.9 h) from one field and very long (35.3 h) from the other. Controversy exists concerning the use of stimulant medication, in part because of a paucity of combat data. A retrospective analysis of 75 pilots who performed 94 combat sorties was performed. The study examined the prevalence of the pilot’s decision to use dextroamphetamine, caffeine, and in-flight sleep during combat. Demographic factors, the impact of one anti-fatigue tool on the use of others, stimulant benefit, and adverse effects were compared. Results showed that pilots on shorter missions used dextroamphetamine for 97% and in-flight naps for 13% of sorties. Those on longer missions used dextroamphetamine on 58% and naps on 94% of sorties. Stimulant use was not affected by pilot age, bomber experience, or long-duration experience. The opportunity to obtain in-flight sleep was limited by certain mission profiles, which influenced the decision to use dextroamphetamine. Among pilots who used the medication, 97% noted a benefit. Side effects and failure to observe benefits were uncommon. B-2 pilots in long duration combat flight selectively employ dextroamphetamine, naps, and other fatigue countermeasures. Major determinants of these decisions are mission requirements and the pilot’s experience with each measure and its effect.

[60] Kenney, A. and Neverosky, D. T. (2004). Quantifying sleep and performance of West Point Cadets: A baseline study. Operations Research, Naval Postgraduate School, Monterey, CA, 105.

The study reports the initial findings of a four-year longitudinal study undertaken to assess the total amount of sleep received by cadets at the United States Military Academy. Specifically, data on the Class of 2007 were collected and analyzed during the freshman year. Survey data were collected (n=1290) on sleep habits prior to the cadets reporting to the Academy. Actigraphy data were collected (n=80) during summer military training and during the Fall academic semester. Survey data were analyzed using two different methods to determine total amount of sleep prior to reporting to the Academy (x =8.5 hrs, s.d.=1.7 hrs; x =7.76 hrs, s.d.=1.46 hrs). Actigraphy data revealed that cadets received much less nighttime sleep (naps not included) during the Fall academic semester than they reported receiving in the 30 days before Cadet Basic Training (total: x =5.32 hrs, s.d.=35.3 mins; school nights: x =4.86 hrs, s.d.= 37.4 mins; non-school nights: x =6.56 hrs, s.d.=64.4 mins). Using morningness-eveningness chronotypes, owls and non-owls differed significantly along the following dimensions: cadet attrition (z=2.66, p=0.0039), fall term academic quality point average (t=3.92, p<0.001), military program score (t=5.169, p<0.001), and physical program score (t=3.295, p=0.001). Suggestions for additional analysis of existing and subsequent data are proposed.

[61] Killgore, W. D. S., Balkin, T. J., and Wesensten, N. J. (2006). "Impaired decision making following 49 h of sleep deprivation." Journal of Sleep Research **15**(1): 7-13.

Thirty-four healthy participants completed the Iowa Gambling Task (IGT) at rested baseline and following 49.5 h of sleep deprivation. After sleep loss, sleep-deprived individuals tended to choose more frequently from risky decks as the game progressed. Although risky decision making was not related to participant age when tested at rested baseline, age was negatively correlated with advantageous decision making on the IGT, when tested following sleep deprivation (i.e. older subjects made more risky choices). These findings suggest that decision making under conditions of uncertainty, may be particularly vulnerable to sleep loss and that this vulnerability may become more pronounced with increased age.

[62] Krueger, G. P. (1989). "Sustained work, fatigue, sleep loss and performance: A review of the issues." Work & Stress **3**(2): 129-141.

The paper describes findings relating to common, sustained work stresses. Researchers report decrements in sustained performance as a function of fatigue, especially during and following one or more nights of complete sleep loss, or longer periods of reduced of fragmented sleep.

[63] Krueger, G. P. (1991). Sustained Military Performance in Continuous Operations: Combatant Fatigue, Rest and Sleep Needs. Handbook of Military Psychology. R. Gal and A. D. Mangelsdorff. Chichester, England, John Wiley & Sons, Ltd.**:** 244-277.

The chapter reviews issues concerning sustained performance and sleep deprivation, and suggests strategies for combatants who engage in continuous military operations.

[64] Krueger, G. P. and Barnes, S. M. (1989). Human performance in continuous/ sustained operations and the demands of extended work/rest schedules: An annotated bibliography - Vol. II. U.S. Army Aeromedical Research Laboratory, USAARL Report No. 89-8, Fort Rucker, AL.

The bibliography includes 182 references containing research data, conceptual position papers, and different methodological approaches to studying human performance in continuous/ sustained operations and extended work/rest schedules. The time period covered is from 1985 to 1989. The study includes a cross subject index for the combined 582 references of both volumes.

[65] Krueger, G. P., Cardenales-Ortiz, L., and Loveless, C. A. (1985). Human performance in continuous/ sustained operations and the demands of extended work/rest schedules: An annotated bibliography. Walter Reed Army Institute of Research, Division of Neuropsychiatry, WRAIR-BB-85-1, Washington, D.C.

The annotated bibliography lists 399 references containing research data, conceptual position papers and different methodological approaches to studying human performance in continuous/sustained operations and extended work/rest schedules. The time frame covered in the references ranges from 1940 to 1985.

[66] LaJambe, C. M., Kamimori, G. H., Belenky, G. L., and Balkin, T. (2005). "Caffeine effects on recovery sleep following 27 h total sleep deprivation." Aviat Space Environ Med **76**(2): 108-13.

The study evaluates caffeine's effects on subsequent recovery sleep and post-recovery performance. Six habitually low (LC: <= 100 mg/d) and three habitually high (HC: >=400 mg/d) caffeine users completed a randomized crossover design. After 20 h of wakefulness, repeated doses of caffeine gum [0 (placebo) mg, 100 (low dose) mg, or 300 (high dose) mg] were administered at 03:00, 05:00, and 07:00. At 10:00 (27 h sleep deprivation) subjects slept for 8 h, followed by Psychomotor Vigilance Task (PVT) administration at 33 and 65 min post-awakening. Results: Low dose caffeine increased stage 1 minutes only. However, high dose caffeine impaired sleep maintenance (reduced total sleep time/increased wake) and reduced sleep depth (increased stage 1 minutes/percentage and slow-wave sleep (SWS) latency, and reduced SWS minutes during the first third of the sleep period). With high dose caffeine, LC users had less SWS percentage as compared with HC users. The HC users had reduced stage 2 percentage with high dose caffeine as compared with placebo and low dose caffeine. Caffeine dose and habitual caffeine use did not influence post-recovery sleep PVT performance. Caffeine exerts mild deleterious dose-response effects on recovery sleep following total sleep deprivation, primarily early in the sleep period, with potential recovery from these effects after sufficient sleep as suggested by lack of post-recovery sleep performance deficits. Habitual caffeine use appears to minimally reduce caffeine effects.

[67] LaJambe, C. M., Sing, H., Thorne, D., Balkin, T., Belenky, G. L., and Wesensten, N. J. (2003). "Morningness-Eveningness differences in sleepiness during 72 hours of sleep deprivation." Sleep **26**(Abstract Supplement): A203-A204.

The study addresses sleep deprivation sensitivity by evaluating subjective and objective sleepiness during a 72-hours wakefulness laboratory-based sleep deprivation study. Participants included fourteen healthy subjects. The study confirms that morning-types are more vulnerable to sleep deprivation than evening-types. This finding is manifested only in objective sleepiness, which suggests that subjective measures of determining physiological sleepiness may not be appropriate for morning-types.

[68] Larsen, R. P. (2001). "Decision making by military students under severe stress." Military Psychology **13**(2): 89-98.

The object of this experiment was to study how young, severely stressed, sleep-deprived military students react and make decisions when ordered to fire with live ammunition at human beings targets and not humanoid dummies. In this experiment, 59% of the students (1st or 2nd Lieutenants) fired their weapons and 41% did not. All of the 41% who did not fire said they noticed people in the target area and therefore did not fire, but only one of them tried to warn the others to stop firing. The results of the study show that the majority of these young, severely stressed, sleep-deprived military students fired, and of those who held their fire, most did not warn others to do the same.

[69] Lavie, P. (1986). Twenty-four hour structure of vigilance under prolonged sleep deprivation: relationship with performance. U.S. Army Research Institute for the Behavioral and Social Sciences, ARI Research Note 86-32, Alexandria, VA.

The study investigates the 36-h structure of sleepiness and its relationship to psychomotor performance after 28-h of sleep deprivation. Eight participants were kept awake from 23:00 till 11:00 next morning. At 11:00 a schedule of 7-min sleep attempt in bed, 13-min awake outside the bedroom, or 7-min resisting sleep in bed, 13-min awake outside the bedroom, was begun and maintained for 36-h until 23-h on the next day. Participants slept 51% of the time in the attempting sleep condition and 46% of the time in the resisting sleep condition. Sleepiness peaks occurred in midafternoon and in night. Less sleepiness was evident at approximately 11:00 and between 19:00 and 21:00. Reaction time and movement time were significantly affected by circadian rhythms. For all degrees of difficulty and every task, performance was poorer in the resisting sleep condition. In spite of the similarity between circadian variations in sleepiness and in performance, correlating these two variables for 12-h blocks revealed random and non-significant correlations. This finding suggests that sleepiness and performance are modulated by a common underlying circadian oscillator.

[70] LeDuc, P. A., Caldwell, J. A., and Tuyak, P. S. (2000). "The effects of exercise as a countermeasure for fatigue in sleep-deprived aviators." Military Psychology **12**(4): 249-266.

This study examined the effectiveness of exercise for sustaining performance despite moderate amounts of sleep, through objective and subjective sleepiness and alertness ratings. Twelve Army aviators (11 men and 1 woman) engaged in 10-min bouts of exercise during one 40-hr period of sleep deprivation and rested for an equivalent amount of time during a 2nd period. Participants were more alert immediately following exercise, as evidenced by longer sleep latencies, than after the resting, control condition. However, electroencephalogram data collected 50 min following exercise or rest showed that exercise facilitated increases in slow-wave activity, signs of decreased alertness. Cognitive deficits and slowed reaction times associated with sleep loss were equivalent in both conditions. The results from this study suggest that short bouts of exercise may ameliorate some of the increases in sleepiness and fatigue associated with sleep loss for a short

period of time but are not likely to prevent performance decrements. In addition, less than 1 hr following exercise, significant increases in fatigue and sleepiness may occur.

[71] LeDuc, P. A. and Caldwell, J. A. J. (1998). A review of the relationships among sleep, sleep deprivation, and exercise. U.S. Army Aeromedical Research Laboratory, USAARL Report No. 98-25, Fort Rucker, AL.

The review assesses some of the problems associated with conducting sleep and exercise studies. The impact of factors such as age, gender, fitness levels of subjects, and duration and intensity of exercise have been examined. In general, the beneficial effects of exercise on sleep are most pronounced if the exercise is aerobic, conducted in the late afternoon, and of moderate duration. Disruptive effects are seen when exercise is too close to bedtime or of extremely long durations. Literature examining the interaction of sleep deprivation/ restriction and exercise on cognitive, physiological, and psychological performance was also investigated.

[72] LeDuc, P. A., Greig, J. L., and Dumond, S. L. (2005). Self-report and ocular measures of fatigue in U.S. Army Apache Aviators following flight. U.S. Army Aeromedical Research Laboratory, Aircrew Health and Performance Division, USAARL Report No. 2005-10, Fort Rucker, AL.

The study goals are to quantify possible flight-induced fatigue in Apache aviators, and evaluate minimally intrusive neurophysiologic measures of fatigue for potential use in operational environments. Self-reported levels of alertness, physical, cognitive and visual fatigue and ocular indices of fatigue were obtained from 54 aviators by using a pre-post design. The day before flight, the aviators reported having obtained 7.1-h (SD=1.5-h) of sleep. Results showed significant differences in all pre- and postflight ocular responses. Significant pre- and post-flight differences were also found on all self-report measures (5% decrease in alertness, 20% in physical, cognitive, and visual fatigue). After flight pilots reported being less alert and more fatigued.

[73] LeDuc, P. A., Riley, D., Hoffman, S. M., Brock, M. E., Norman, D. N., Johnson, P. A., Williamson, R., and Estrada, A. (1999). The effects of sleep deprivation on spatial disorientation. U.S. Army Aeromedical Research Laboratory, USAARL Report No. 2000-09, Fort Rucker, AL.

The study investigates the effects of fatigue on aviator response to in-flight, disorienting events. Eight UH-60 rated aviators participated. Analyses showed that nearly all measures of performance, including mood, alertness, cognition, spatial orientation, postural stability, flight accuracy, and recovery from in-flight disorientation, were detrimentally impacted by fatigue.

[74] Lieberman, H. R., Bathalon, G. P., Falco, C. M., Morgan, C. A., 3rd, Niro, P. J., and Tharion, W. J. (2005). "The fog of war: decrements in cognitive performance and mood associated with combat-like stress." Aviat Space Environ Med **76**(7 Suppl): C7-14.

The study evaluates cognitive function in warfighters engaged in exercises designed to simulate the stress of combat. These studies were conducted in different environments with two different types of military volunteers. In one study, subjects were officers, with an average 9 yr of military service, who were members of U.S. Army Rangers unit. In the other study, participants were younger, mostly enlisted, trainees with only 3 yr of military experience on average, in training to determine if they would qualify for U.S. Navy SEAL units. A variety of identical, computer-based cognitive tests to both groups were administered. Results showed that in both groups, during stressful combat-like training, every aspect of cognitive function assessed was severely degraded compared with baseline, pre-stress performance. Relatively simple cognitive functions such as reaction time and vigilance were significantly impaired, as were more complex functions, including memory and logical reasoning. The deficits observed were greater than those typically produced by alcohol intoxication, treatment with sedating drugs, or clinical hypoglycemia. Rangers had on average 3.0-h of daily sleep, whereas SEALs during the Hell Week were almost totally sleep deprived. Undoubtedly, such decrements would severely degrade operational effectiveness. Furthermore, it is likely such cognitive decrements would be greater during actual combat. War planners, doctrine developers, and warfighters, especially leaders, need to be aware that combat stress will result in extensive and severe deficits in cognitive performance.

[75] Lieberman, H. R., Niro, P., Tharion, W. J., Nindl, B. C., Castellani, J. W., and Montain, S. J. (2006). "Cognition during sustained operations: comparison of a laboratory simulation to field studies." Aviat Space Environ Med **77**: 929-35.

The study developed a brief, intense, laboratory-based simulation of a multistressor environment which included sleep loss, continuous physical activity, and food deprivation. During this sustained operations (SUSOPS) scenario and a control period, cognitive performance and mood were measured in 13 volunteers. The scenario included road marches, battle drills, and land navigation. Physical activity and sleep were assessed with actigraphs. Results showed significant decrements in visual vigilance, choice reaction time, and matching-to-sample, a test of short-term memory. Marksmanship was stable and physical activity significantly increased. Mood states assessed by the Profile of Mood States (POMS: Tension, Depression, Anger, Vigor, Fatigue and Confusion) also significantly deteriorated. Cognitive function declined more extensively and rapidly than physical performance. Decrements in cognitive performance were comparable to those in a field study conducted for an equivalent period of time in uncontrolled conditions. This demonstrates that decrements in cognitive function and increased physical activity, similar to those in highly stressful field environments, can be duplicated under controlled conditions. The simulated SUSOPS scenario is an appropriate paradigm for assessment of adverse effects of

military and civilian multistressor environments on human performance, physiology, and interventions designed to mitigate them.

[76] Lieberman, H. R., Tharion, W. J., Shukitt-Hale, B., Speckman, K. L., and Tulley, R. (2002). "Effects of caffeine, sleep loss, and stess on cognitive performance and mood during U.S. Navy SEAL training." Psychopharmacology **164**: 250-261.

The study examined whether moderate doses of caffeine would reduce adverse effects of sleep deprivation and exposure to severe environmental and operational stress on cognitive performance. Volunteers were 68 U.S. Navy Sea-Air-Land (SEAL) trainees, randomly assigned to receive either 100, 200, or 300 mg caffeine or placebo in capsule form after 72 h of sleep deprivation and continuous exposure to other stressors ("Hell Week"). Cognitive tests administered included scanning visual vigilance, four-choice visual reaction time, a matching-to-sample working memory task and a repeated acquisition test of motor learning and memory. Mood state, marksmanship, and saliva caffeine were also assessed. Testing was conducted 1 and 8 h after treatment. Results show that sleep deprivation and environmental stress adversely affected performance and mood. Caffeine, in a dose-dependent manner, mitigated many adverse effects of exposure to multiple stressors. Caffeine (200 and 300 mg) significantly improved visual vigilance, choice reaction time, repeated acquisition, self-reported fatigue and sleepiness with the greatest effects on tests of vigilance, reaction time, and alertness. Marksmanship, a task that requires fine motor coordination and steadiness, was not affected by caffeine. The greatest effects of caffeine were present 1 h post-administration.

[77] Luna, T. D., French, J., and Mitcha, J. L. (1997). "A study of USAF air traffic controller shiftwork: sleep, fatigue, and mood analyses." Aviat Space Environ Med **68**(1): 18-23.

The study evaluates the shift-specific sleep, general activity levels, mood and cognitive performance of air traffic controllers (ATCs) working a forward 2-2-2 rapid rotation shift schedule. ATCs recorded their sleep, oral temperature and subjective fatigue levels, took a computerized cognitive performance battery (n=13) and completed the Profile of Mood States questionnaire (POMS) (n=12). Actigraphs were used to objectively monitor general activity levels and score sleep and the restfulness of scored sleep (n=9). Analyses were made on the basis of duty shift, post-shift, day of shift, and duty location. Results showed that there was significant more actigraph scored sleep (85 min, p=0.038), subjectively reported sleep (26 min, p=0.009) and subjectively measured fatigue (p<0.001) and confusion (p=0.003) for the ATCs while they were on duty on the night-shift. The night-shift was also associated with decreased vigor (p=0.039) and general activity levels (p=0.017). Significantly more sleep was reported (7.6 h, p=0.01) and scored by actigraph (4.7 h, p=0.02) following the swing-shift than following the day-shift. The radar approach ATCs reported greater confusion (p=0.019) and less vigor (p=0.002) than the tower ATCs. Insufficient trials were available for direct performance analysis. ATCs on the night-shift of a forward rapid rotation shift schedule appear to be falling asleep and report increased confusion and fatigue.

[78] Majors, J. S. (1984). Human Factors Survey: C-5 Pilots. USAF School of Aerospace Medicine, USAFSAM-TR-84-26, Brooks City-Base, TX.

Thirty-four C-5 pilots participated in the study to evaluate human factors issues on MAC C-5s. The chronic problem of airlift-crew fatigue is apparent. Moderate-to-extreme fatigue level during typical leg of most strategic airlift missions was reported by 55.9% of the pilots; problems with various cognitive skills or information processing, 23.5%; significant anomalies of attention, 55.9%; recent significant changes in moods/ emotions, 20.6%.

[79] McLellan, T. M., Bell, D. G., and Kamimori, G. H. (2004). "Caffeine improves physical performance during 24 h of active wakefulness." Aviat Space Environ Med **75**(8): 666-72.

BACKGROUND: Reductions in both cognitive and physical performance occur during periods of sleep loss with sustained operations. It was the purpose of this study to examine the effects of caffeine on activities chosen to simulate the physical challenges that might occur during a military scenario involving a period of sleep loss. METHODS: There were 16 subjects (26.7 +/- 7.8 yr, 83.8 +/- 11.0 kg) who completed a double-blind caffeine and placebo trial involving a control day and sleep period followed by 28 h of sleep deprivation. A 400-mg dose of caffeine was administered at 21:30 followed by subsequent 100-mg doses at 03:00 and 05:00. At 22:00, subjects began a 2-h forced march followed by a sandbag piling task. A treadmill run to exhaustion at 85% of maximal aerobic power was performed at 07:00 of the second day of sleep deprivation. RESULTS: Caffeine had no effect on the heart rate or oxygen consumption, but rating of perceived exertion (RPE) was reduced with caffeine during the forced march. Time to complete the sandbag piling task during set 1 was significantly reduced with caffeine (12.9 +/- 1.0 min) compared with placebo (13.8 +/- 1.0 min) but there was no difference during set 2 and RPE was increased. Time to exhaustion was significantly increased 25% during the run with caffeine (17.0 +/- 4.4 min) compared with placebo (13.5 +/- 3.3 min), and caffeine maintained performance at control levels (16.9 +/- 4.6 min). CONCLUSIONS: It was concluded that caffeine is an effective strategy to maintain physical performance during an overnight period of sleep loss at levels comparable to the rested state.

[80] McLellan, T. M., Kamimori, G. H., Bell, D. G., Smith, I. F., Johnson, D., and Belenky, G. (2005). "Caffeine maintains vigilance and marksmanship in simulated urban operations with sleep deprivation." Aviat Space Environ Med **76**(1): 39-45.

PURPOSE: The purpose of this study was to examine the effects of caffeine (CAF) on physical, vigilance, and marksmanship tasks in soldiers during a sustained 55-h field exercise. METHODS: There were 30 soldiers (23.6 +/- 4.5 yr, 81.8 +/- 10.3 kg) who were divided into a placebo (PLAC) and a CAF group. After a period of restricted sleep of 3 h during the first night, a period of sustained wakefulness began that ended at 11:00 of the third day. PLAC or CAF doses of

100 mg, 200 mg, 100 mg, and 200 mg were administered at 21:45, 23:45, 01:45, and 03:45, respectively. At 22:00 of day 2, subjects began two cycles of marksmanship, urban operations vigilance, and psychomotor vigilance (PVT) testing which ended at 06:00 of day 3. RESULTS: CAF maintained marksmanship vigilance at 85% throughout the second night as compared with PLAC, who significantly declined to 61.4 +/- 28.2% overnight. Marksmanship accuracy also decreased significantly in PLAC from 95.1 +/- 8.3% to 83.3 +/- 19.2%, but no change was observed in CAF. Urban operations vigilance decreased for both groups over the night, but the decrease was less for CAF (81.2 +/- 14.4% to 63.4 +/- 24.1%) compared with PLAC (77.6 +/- 19.2% to 44.0 +/- 30.2%). Reaction time and the number of major and minor lapses with the PVT significantly increased in PLAC but were unaffected in CAF. CONCLUSIONS: It was concluded that CAF was an effective strategy to sustain vigilance and psychomotor performance during military operations involving sleep deprivation.

[81] McLellan, T. M., Kamimori, G. H., Voss, D. M., Bell, D. G., Cole, K. G., and Johnson, D. (2005). "Caffeine maintains vigilance and improves run times during night operations for Special Forces." Aviat Space Environ Med **76**(7): 647-54.

This study examined the effects of caffeine (CAF) on vigilance, marksmanship, and run performance during 27 h of sustained wakefulness in Special Forces personnel. There were 31 soldiers (29.8 +/- 5.4 yr, 86.4 +/- 8.6 kg) who were divided into placebo (PLAC, n = 15) and CAF (n = 16) groups. A 6.3-km control run was completed on the morning of Day 1. In the evening of Day 2, soldiers performed a control observation and reconnaissance vigilance task (ORVT) in the field. This 90-min task was repeated twice more between 02:00 and 06:00 on Day 3 during an overnight period of sleep deprivation. Marksmanship was assessed before and after the ORVT. PLAC or 200 mg of CAF gum was administered at 01:45, 03:45, and approximately 06:30 on Day 3. A final 6.3-km run commenced within 30 min of receiving the final dose. ORVT was maintained in CAF at control levels of 77 +/- 13% during the overnight testing. However, values decreased significantly for PLAC from 77 +/- 15% to 54 +/- 29% and 51 +/- 31% during the first and second overnight testing periods, respectively. CAF had no effect on marksmanship but improved 6.3-km run times by 1.2 +/- 1.8 min. Run times slowed for PLAC by 0.9 +/- 0.8 min from approximately 35 min during the control run; the changes in performance were significant between groups. It was concluded that CAF maintained vigilance and improved running performance during an overnight field operation for Special Forces personnel.

[82] Meyer, L. G. and DeJohn, C. A. (1990). Sustained Flight Operations in Navy P-3 Aircraft. Naval Aerospace Medical Research Laboratory, Naval Air Station, NAMRL-1355, Pensacola, FL.

The study evaluates the effects of SUSOPS on aircrew stress and fatigue in three U.S. Navy P-3 Orion crews (n=21) before, during, and after a 6-month overseas deployment. During the deployment the participants completed 11 SUSOPS ASW missions with duration from 9 to 15 hours. Subjective fatigue scores decreased from preflight to postflight. Positive mood scores decreased while negative mood

scores increased. Participants showed varying levels of stress and fatigue, which did not appear to compromise performance and safety. Overall, the 15-h non-flying intervals between flights provided sufficient rest for the crews.

[83] Miller, D. B. (2005). Sleep and predicted cognitive performance of new cadets during cadet basic training and the United States Military Academy. Modeling, Virtual Environments and Simulation, Naval Postgraduate School, Monterey, CA, 141.

The study investigates the amount of daily sleep received by New Cadets during Cadet Basic Training (CBT) at the United States Military Academy. Sleep was measured using actigraphy on a stratified sample of 80 New Cadets. The results indicated that New Cadets slept an average of approximately 340 minutes or 5 hours, 40 minutes per night. The results were compared to self-reported survey data to determine whether sleep prior to arrival at West Point matched measured sleep at CBT. The findings indicate that the study population is sleep-deprived during CBT. The study population was sleeping on average 2 hours, 6 minutes less per night during CBT than prior to their arrival at West Point. The findings also indicate that the amount of sleep was not related to gender, race, cadet company assignment, age, recruited athlete status, or circadian chronotype (Morningness/Eveningness preference).

[84] Miller, J., Smith, M. L., and McCauley, M. E. (1999). Crew fatigue and Performance on U.S. Coast Guard Cutters. U.S. Department of Transportation, United States Coast Guard, CG-D-10-99, Washington, D.C.

The study evaluates crew fatigue onboard USCG cutters. The approach included assessments of workload, effort, performance, and fatigue of selected crew members on three types of USCG cutters during six operational, no high tempo, patrols (with no manipulations of work conditions). Approximately 10% to 45% of crew members displayed one or more signs of mild fatigue. Watchstanders averaged 9.7-h of work per day while non-watchstanders averaged 8.3-h. The crew members acquired adequate sleep with respect to their self-reported ideal amounts, but the quality was questionable because a) there were more than one sleep episodes daily, and b) vigilance was found to be impaired. Pattern matching performance, vigilance, and temporal visual acuity all declined from day to day, though the crew members reported no perceptions of accumulating fatigue.

[85] Murphy, P. J. (2002). Fatigue Management during Operations: A Commander's Guide. Puckapunyal, Victoria, Australia, Doctrine Wing, Land Warfare Development Center.

The guide includes an introduction to sleep parameters. It reviews lessons learned and gives guidance on sleep and fatigue management in military operations. Special sections note results from operations in Somalia, Bosnia, and East Timor, were fatigue due to sleep deprivation was a major contributor to warfighters performance decrease.

[86] Myles, W. S. and Romet, T. T. (1987). "Self-paced work in sleep deprived subjects." Ergonomics **30**(8): 1175-1184.

The study examines sleep deprivation and physical fatigue effects on self-paced work during simulated combat engineer operations. The first experiment involved four participants for 69-h with any sleep. During this period they performed only four physically demanding tasks, three of them in the last 24-h. The second experiment involved six participants carrying out a full schedule of physically demanding tasks during a sleep deprivation period of 47-h. Results from the first experiment showed that sleep deprivation, in the absence of physical fatigue, had no effect on work intensity and the period of fatiguing work (heart rate above 120 beats per minute). Results from the second experiment, showed that for the first 14-h the subjects worked at an average of 35-40% of maximal oxygen uptake in fit young men. In the remainder of the sustained operation, work intensity declined and the participants worked at heart rates above 120 beats per minute for shorter periods. Rating scales confirmed that these changes coincided with the development of physical fatigue.

[87] Naitoh, P. (1989). Minimal sleep to maintain performance: search for sleep quantum in sustained operations. Naval Health Research Center, NHRC Report No. 89-49, San Diego, CA.

The report is a review of research findings on the minimal amount of sleep needed to maintain a high level of task performance. The paper addresses applications of sleep management, and basic issues such as minimal sleep duration, impact of time of day when sleep is taken, continuous sleep ultra short sleep episodes etc. According to the review minimal sleep is found to be approximately 5-h per 24-h. Finally, the paper recommends ultra short sleep as the means to maintain high level of performance in SUSOPS.

[88] Naitoh, P. and Angus, R. G. (1987). Napping and human functioning during prolonged work. Naval Health Research Center, NHRC Report No. 87-21, San Diego, CA.

The paper is a literature review of naps' effectiveness as a counter-degradation measure. Furthermore, the paper addresses the issue of sleep management and evaluates of studies conducted at the Defence and Civil Institute of Environmental Medicine, Canada and the Naval Health Research Center.

[89] Naitoh, P., Englund, C. E., and Ryman, D. H. (1986). Sleep management in sustained operations user's guide. Naval Health Research Center, 86-22, San Diego, CA.

Overview of sleep management benefits in SUSOPS. It a) discusses the challenge to sustain combat effectiveness in SUSOPS, b) defines what SUSOPS and sleep management is, c) reviews how the problem can be identified, performance degradation be prevented, and ways the problem can be overcome, and d) details techniques to manage sleep in field training.

[90] Naitoh, P., Englund, C. E., and Ryman, D. H. (1987). Sustained Operations: Research results. Naval Health Research Center, NHRC Report No. 87-17, San Diego, CA.

The effects of a laboratory simulated reconnaissance operation on behavioral and physiological performance were assessed in seven separate SUSOPS studies, conducted between 1979 and 1985, involving a total of 112 U.S. Marine Corps volunteers. The scenario of the week-long SUSOP involved two 20-h continuous work episodes with a break of 3 to 4 hours of sleep or rest. One half of the participants experienced 30%-40% VO2Max physical work load by walking on a motor-driven treadmill. All participants performed psychological cognitive tasks. The results suggested that (1) starting time of a mission should be chosen to avoid extending a continuous work period into early morning hours of circadian trough, (2) a 3-4 hour nap is not long enough to allow recovery from fatigue of a 20-h continuous work episode to maintain a baseline level of performance during successive continuous work episodes, (3) a physical workload of 30% or greater VO2Max will slow down reaction time post physical work period, and (4) time-of-nap is not as important as the duration of the nap. Management of sleep (nap) is recommended in redefining the limits of human endurance in any SUSOP.

[91] Naitoh, P., Kelly, T., and Babkoff, H. (1990). Napping, stimulant, and four choice performance. Naval Health Research Center, NHRC Report No. 90-17, San Diego, CA.

The study determines the effectiveness of napping in preventing performance degradation during a continuous work due to sleep loss and compares this with that of a stimulant, pemoline (Cylert). The nap schedule consisted 20-min naps every 6-h for 64 continuous hours. The pemoline dose of 37.5 mg was administered in a double blind manner every 12-h. Results show that the 20-min naps, as well 37.5 mg doses of pemoline taken prophylactically before the accumulation of sleep debt, were able to prevent cognitive decrements in response accuracy. The 20-min naps were not as effective as pemoline, but helped to reduce the effect of sleep loss. In Four Choice task neither napping nor pemoline prevented performance decline (because it is a self-paced task and, thus, dependent on the participants' willingness to keep responding).

[92] Naitoh, P., Kelly, T., and Babkoff, H. (1992). Sleep inertia: Is there a worst time to wake up? Naval Health Research Center, 91-45, San Diego, CA.

The study examines whether sleep inertia shows a circadian rhythmicity. Subjects (n=19) underwent either a 64-h without sleep (n=10) or a 64-h with a 20-min nap period every 6-h (n=9). Sleep inertia was measured by performance scores of Baddeley's logical reasoning task. The effects of sleep inertia were found to be additive to those of sleep deprivation. The napped subjects showed inferior logical reasoning performance during a post-nap 6-min period, compared with totally sleep deprived subjects. The severity of sleep inertia effects on performance were found not to show circadian variation, however, waking up from naps during the circadian temperature through was psychologically very difficult for the subjects. Furthermore, it was found that sleep inertia depended on the sleep stages from which the subjects were awakened. The results suggest that resuming work interrupted by a nap should occur at least 10 minutes after waking up.

[93] Naitoh, P., Kelly, T., and Englund, C. E. (1990). "Health effects of sleep deprivation." Occupational Medicine **5**(2): 209-237.

Purpose of the review is to survey and review the results of laboratory and field studies on health consequences of sleep loss. The paper describes and evaluates the available database to determine the effects of different kinds of sleep loss on the functional integrity of the human organism. The factors discussed include: adrenomedullary activity, adrenocortical activity, metabolism, hematological and immunological changes, autonomic nervous system activity, epilepsy, physical working capacity, antidepressant effects, and mental health.

[94] Naitoh, P. and Ryman, D. H. (1985). Sleep management for maintenance of human productivity in continuous work schedules. Naval Health Research Center, 85-43, San Diego, CA.

The study evaluates task performance during sustained operations. Three groups of U.S. Marines were evaluated for effects of starting time, exercise, time-on-job, and sleep duration on their task performance. The morning group (n=22) started a 45-h long continuous operation at 08:00, the noon group (n=16) started at 13:00, and the midnight group (n=16) started at 00:00. The 45-h work period was divided into the first 20-h long continuous workday, followed by 5-h break (included a 3-h nap), and then by a second 20-h continuous workday. In each group half of the participants were chosen to walk on a treadmill for half an hour of every working hour. The NHRC Performance Assessment Battery was used to measure psychomotor and cognitive efficiency. The results show that: 1) the subjects in the noon group showed significantly slower simple reaction and four-choice reaction times in comparison with the morning and midnight groups, hence the starting time of workday makes a critical difference in maintaining performance effectiveness, 2) exercise at 30% of maximal aerobic power significantly slowed the reaction time and caused more errors in the simple reaction and four-choice reaction task times. Post-exercise psychomotor task performance was slower and less accurate for exercising as compared to non-exercising, 3) the 30-h long nap was not sufficiently long enough to assure continued high performance, 4) all participants could maintain the same performance level up to 12-h during the first workday.

[95] Neri, D. F. and Shappell, S. A. (1993). Work/Rest Schedules and Performance of S-3 Aviators during Fleet Exercise 1992. Naval Aerospace Medical Research Laboratory, NAMRL-1382, Pensacola, FL.

The study examines the effect of a fleet exercise on the work/rest patterns, fatigue, and cognitive performance of S-3 aviators. For 10 days during Fleet Exercise 1992, 21 S-3 aviators from Carrier Air Wing Seventeen (CVW-17) aboard USS SARATOGA completed detailed daily-activity logs while performing their usual tasks. Subjective measures of fatigue, quality of rest, and sleep need were measured. A subset of 8 aviators completed a battery of computer tests before and after flying. Results indicated that, although fleet exercise appeared to be below average in difficulty and physical challenge, there were significant performance decrements in reaction time task. Nevertheless, aviators had ample opportunity for adequate sleep and rest. The mean reported sleep amount ranged from 5.5-h to 8.0-h (from sleep logs). Average sleep onset was delayed over the course of fleet exercise, peaking at past 03:00 by day 8. A continuation of this pattern could lead to circadian desynchrony. Responses to questions on fatigue, sleep need, and readiness to fly a strike mission were consistent with circadian factors.

[96] Neri, D. F. and Shappell, S. A. (1994). "The effect of combat on the work/rest schedules and fatigue of naval aviators during operations Desert Shield and Desert Storm." Military Psychology **6**(3): 141-162.

For two weeks during operations Desert Shield and Desert Storm, 23 naval aviators (12 A-6 and 11 F-14 aircrew) aboard the USS AMERICA participated in the study to evaluate work/rest schedules of naval aviators in combat and to examine subjective fatigue and sleep problems. The mean work day reached almost 12-h, and the work/rest/sleep activities were similar for both types of aircrafts. A-6 aircrews pattern were affected by the different operations. The aviators flew frequently at night without significant sleep problems or fatigue. A likely factor was the large number of assets in the combat theater, allowing workload to be shared. Raster plots of sleep periods suggest another contributing factor: The America's eastward travel from the East Coast through seven time zones may have benefited aircrew who were flying at night. If aircrew's circadian clocks had not fully adapted to local time on arrival in the Red Sea, then flights occurring at 0300 local time (2000 EST) were closer to being less-demanding evening flights by the body's internal clock. The results suggest that incorporating information about the circadian phase of combatants into battle strategy may better prepare them to fight at suboptimal times.

[97] Neri, D. F., Shappell, S. A., and DeJohn, C. A. (1992). "Simulated sustained flight operations and performance, Part 1: Effects of fatigue." Military Psychology **4**(3): 137-155.

Twelve male marines were used to assess changes in cognitive performance on successive long-range attack missions (simulated sustained operations) through repeated cognitive and performance tests. The scenario consisted of a 9-hour planning session followed by a 4-hour rest period and a 14-hour daytime mission. After 6 hours of rest, the scenario was repeated with a night time mission. As the study progressed, subjects appeared to change strategy, possibly exchanging a higher failure rate for decreased reaction times.

[98] Neville, K. J., Bisson, R. U., French, J., Boll, P. A., and Storm, W. F. (1994). "Subjective fatigue of C-141 aircrews during Operation Desert Storm." Human Factors **36**(2): 339-49.

Airlift crews were exposed to extended work periods, reduced sleep periods, night work, and circadian dysrhythmia caused by shift work and time-zone crossings during Operations Desert Shield and Desert Storm. This research reveals the extent to which severe subjective fatigue was experienced by the crews during Operation Desert Storm. In addition, through the evaluation of long-term and short-term work and sleep histories, this research shows that recent sleep and flight histories are correlated with high fatigue levels. Furthermore, a tendency was found for fatigue to correspond with pilot error. It is recommended that the training of personnel involved in long-duration operations include fatigue management strategies and, further, that work policies and environments be designed to take into account the importance of regular and restorative sleep when unusual duty hours are required.

[99] Nguyen, J. L. (2002). The effects of reversing sleep-wake cycles on sleep and fatigue on the crew of USS JOHN C. STENNIS. Operations Research, Naval Postgraduate School, Monterey, CA, 169.

The study explores the effects of reversing the work-sleep schedules of the crew aboard the USS JOHN C. STENNIS. It also reviews current research in the field of sleep deprivation and the resultant performance decrements in humans. The results of the study indicate 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 below decks. Using a validated model of human performance and fatigue, we demonstrate that the level of fatigue and sleep deprivation observed in this study population significantly reduces individual effectiveness. The recommendations address the need for educating military personnel on the subject of fatigue and sleep logistics, possible fatigue countermeasures, and the need for further research on this topic.

[100] Nicholson, A. N. (1984). "Long-range air capability and the South Atlantic campaign." Aviat Space Environ Med **55**: 269-70.

The article reviews issues concerning the long-range air capability during the South Atlantic campaign at Falklands. The article addresses the faced need for extensive flying rates, which led to repeated increase in the permissible limits, the sleep disruption, and the use of hypnotics to overcome the detrimental effects of fatigue and sleepiness.

[101] Nicholson, A. N., Roth, T., and Stone, B. M. (1985). "Hypnotics and aircrew." Aviat Space Environ Med **56**: 299-303.

The article gives an overview of pharmacokinetics related to hypnotics used in management of sleep difficulties during air operations. The article discusses issues such as persistence of effect, the potential for accumulation with repeated ingestion, and efficacy in relation to sleep of different duration and age. Finally, it makes some recommendations about the use of hypnotics in operational settings.

[102] Paley, M. J. and Tepas, D. I. (1994). "Fatigue and the Shiftworker: Firefighters working on a rotating shift schedule." Human Factors **36**(2): 269-284.

> The study examines reductions in sleep length associated with shiftwork. There were 20 male firefighters which concluded one rotation cycle of shiftwork, each one consisting of three two-week periods (one period in night shift, one in evening shift, and one in morning shift). The firefighters who worked on an 8-hour shift schedule slept less and reported lower positive mood scores, higher negative mood scores, and greater sleepiness ratings on the night shift when compared to the other shifts. It was shown that over the course of a shift (two weeks) firefighters were unable to adapt to changes in their sleep schedule.

[103] Patton, J. F., Vogel, J. A., Damokosh, A. I., and Mello, R. P. (1987). Effects of continuous military operations on physical fitness capacity and physical performance. U.S. Army Research Institute of Environmental Medicine, Natick, MA.

> The study evaluates physical fitness capacity and performance during a continuous artillery scenario. Twenty-four artillery men in three 8-man gun crews participated in an 8-day combat simulated operation. Physical performance scores were significantly higher on days 1 and 8 compared to the other days. Mean daily sleep was 5.3 hours (SD=1.3 hours). The participants averaged 22 min and 2.9 min per day, respectively, at heart rate equal to or greater than 50% and 75% of their maximal heart rates. The results suggest that soldiers who are allowed 5 hours of daily sleep and who are required to perform at relatively moderate levels of physical intensity show no decrements in physical fitness capacity or evidence of physical fatigue for up to 8 days of continuous of operations.

[104] Paul, M. A., Pigeau, R. A., and Weinberg, H. (1998). Human Factors of CC-130 Operations. Volume 6: Fatigue in long-haul re-supply missions. Defence and Civil Institute of Environmental Medicine, DCIEM No.98-R-19, New York, Ontario, Canada.

> The study is an attempt to document to what extent fatigue (and time zone changes) impact aircrew performance during 10 routine re-supply missions from Trenton (Canada) to Zagreb (Croatia) involving 53 aircrew subjects. The flight included two legs (Trenton to Lyneham, UK, and Lyneham to Zagreb). Results show that sleep amount during the days leading to a mission steadily decreased from and average of 475-min per day to an average of 380-min, with 25% of the participants getting less than 6-h and some obtaining as little as 250-min per day on the last pre-mission night at home. The worst mission night of sleep occurred during the second night in the U.K. Subjective ratings of alertness and fatigue became progressively worse during both transatlantic legs. Data from multi-task battery (analogous to a flying task) depicted fatigue-related lapses in performance on both transatlantic legs showing performance ranging from minimum to marked impairment.

105] Paul, M. A., Pigeau, R. A., and Weinberg, H. (2001). "CC-130 pilot fatigue during re-supply missions to former Yugoslavia." Aviat Space Environ Med **72**(11): 965-73.

Deployment of troops in foreign theaters requires a massive airlift capability. The fatigue encountered in such operations can be severe enough to pose a flight safety hazard. The current study documents sleep and the effect of fatigue on aircrew performance during re-supply missions in support of Canadian troops in Bosnia in 1996. Ten routine re-supply missions from Trenton, Canada, to Zagreb, Croatia, were studied and involved 9 pilots and 9 co-pilots. To document their sleep hygiene, all pilots wore wrist actigraphs from approximately 5 d prior to the mission, until the mission was completed. Psychomotor performance was tested during the actual flights. Three psychomotor trials during the outbound transatlantic leg (Trenton to Lyneham, UK) were employed, one trial on the Lyneham-Zagreb-Lyneham leg, and three trials on the return transatlantic leg from Lyneham to Trenton. The amount of daily sleep during the 3-d period prior to the mission steadily decreased from an average of 8 h 40 min per day to 6 h 30 min ($p < 0.001$). During the missions, the worst night of sleep occurred during the second night overseas. During both transatlantic legs, there were significant decrements in the subjective ratings of alertness ($p < 0.001$), and increases in physical ($p < 0.001$) and mental fatigue ($p < 0.001$). Performance on the logical reasoning task as well as the multitask showed probable fatigue effects during the outbound leg of the missions. The transport pilots showed a pattern of progressively decreasing sleep. Self-rated scores for alertness, mental and physical fatigue, indicate a deterioration of alertness, and an increase in fatigue throughout the long transatlantic flights.

[106] Pigeau, R., Angus, B., and O'Neil, P. (1995). "Vigilance latencies to aircraft detection among NORAD surveillance operators." Human Factors **37**(3): 622-634.

Sixteen Canadian NORAD surveillance operators participated in a vigilance study to investigate the relationship among coverage, time on task, and shift, while the operators were engaged in their normal work schedule. Vigilance decrements were evident in the detection task the operators were conducting, but the effect is less pervasive than the one reported in laboratory studies and limited, largely, to individuals working the midnight shift.

[107] Pilcher, J. J. and Huffcutt, A. I. (1996). "Effects of sleep deprivation on performance: a meta-analysis." Sleep **19**(4): 318-326.

This study is a meta-analysis of 19 research studies into the effects of sleep deprivation. Studies were selected based on whether they provided the statistics required (i.e., means and standard deviations for sleep deprived and non sleep deprived groups). They had to involve short-term sleep deprivation (<45 hours), long-term sleep deprivation (>45 hours) or partial sleep deprivation (<5 hours in a 24 hour period). The studies also had to use a cognitive performance task, a motor performance task, or a mood scale. Results of 143 study coefficients and a total sample size of 1932 suggest that sleep deprivation strongly impairs human performance, with sleep deprived subjects performing 1.37 standard deviations

lower than non sleep deprived subjects indicating that a sleep deprived subject in the 50th percentile performs at the same level as a non sleep deprived subject in the 9th percentile. The length of sleep deprivation had a significant effect on performance in various different sorts of tasks. Short-term sleep deprivation has the greatest effect on complex and long tasks. Long-term sleep deprivation affects performance on short and simple tasks. Partial sleep deprivation is the most detrimental on simple and long tasks. Partial sleep deprivation had a greater effect on performance than either short or long-term sleep deprivation, with partially sleep deprived subjects performing at a level two standard deviations lower than nonsleep deprived subjects, compared with one standard deviation for short and long-term sleep deprived subjects.

[108] Pleban, R. J. and Mason, T. L. (1996). Characterization of sleep, mood, and performance patterns in Battalion Staff Members at the Joint Readiness Training Center. U.S. Army Research Institute for the Behavioral and Social Sciences, Research Report 1693, Alexandria, VA.

The study evaluates the sleep/work patterns of 10 members of a battalion staff during a low-intensity conflict scenario. Sleep patterns were recorded with wrist-worn activity monitors over a period of 16 days. Data on staff sleep and perceptions of work load were evaluated through questionnaires, whereas daily estimates of cognitive work capacity was obtained using a computerized synthetic work task. Results show that the average daily sleep obtained by the staff members was 5.2-h (range 3.5-h to 6.4-h). Certain staff positions received very little sleep across the exercise. Over 60% of the sleep obtained was fragmented in nature (sleep periods of 10 minutes or less). The research suggests that to effectively sustain staff performance during continuous operations, commanders must take an active role in the development and implementation of unit sleep/work management plans.

[109] Pleban, R. J., Valentine, P. J., Penetar, D. M., Redmond, D. P., and Belenky, G. L. (1990). "Characterization of sleep and body composition changed during ranger training." Military Psychology **2**(3): 145-156.

Fifteen U.S. Army soldiers were outfitted with wrist-worn, solid-state activity monitors and had body weight and physical measurements taken while undergoing a 58-day, four-phase Ranger training course. Records from the activity monitors indicated that the average daily sleep obtained by the soldiers was 3.2 hr. Average daily sleep by training phase was: Fort Benning - 3.5 hr, mountain-3.9 hr, swamp-2.6 hr, and desert-3.0 hr. Average weight at the first weigh-in was 178.2 lb with a body fat composition of 14.7%. At the final weigh-in, average weight was 169.7 lb; body fat, however, was essentially the same at 14.3%. This suggests that the weight loss may be due to a reduction in lean body mass, indicative of the stresses placed on the soldiers during training. Sleep was not accrued in a single sleep period, but rather occurred as several naps over each 24 hours.

[110] Quant, J. R. (1992). "The effect of sleep deprivation and sustained military operations on near visual performance." Aviat Space Environ Med **63**(3): 172-6.

> A group of military servicemen were deprived of sleep for 65 h while they carried out a simulated military mission with a high visual workload. Their performance in a series of near vision tests was monitored. In general, the visual system was found to be resilient to the stress of sleep loss, the subjects experiencing mild symptoms of asthenopia (eyestrain). However, after 48 h without sleep there was a reduction in amplitude of convergent fusional reserves and a decrease in contrast sensitivity to a spatial frequency of 6 cycles/degree. A disruption in diurnal rhythms for these parameters was suggested. The results are considered in terms of the maintenance of visual efficiency and comfort with loss of sleep, and have implications for both the military and civilians involved in shift work and long work schedules.

[111] Rosekind, M. R., Co, E. L., Gregory, K. B., and Miller, D. L. (2000). Crew factors in flight operations XIII: A survey of fatigue factors in corporate/executive aviation operations. NASA Ames Research Center, NASA/TM-2000-209610, Moffett Field, CA.

> Corporate flight crews face unique challenges including unscheduled flights, quickly changing schedules, extended duty days, long waits, time zone changes, and peripheral tasks. Most corporate operations are regulated by Part 91 FARs which set no flight or duty time limits. The objective of this study was to identify operationally significant factors that may influence fatigue, alertness, and performance in corporate operations. In collaboration with the National Business Aircraft Association and the Flight Safety Foundation, NASA developed and distributed a retrospective survey comprising 107 questions addressing demographics, home sleep habits, flight experience, duty schedules, fatigue during operations and work environment. Corporate crew members returned 1,488 surveys. Respondents averaged 45.2 years of age, had 14.9 years of corporate flying experience, and 9750 total flight hours. The majority (89%) rated themselves as "good" or "very good" sleepers at home. Most (82%) indicated they are subject to call for duty and described an average duty day of 9.9-h. About two-thirds reported having a daily duty time limit and over half (57%) reported a daily flight time limit. Nearly three quarters (71%) acknowledged having a "nodded off" during flight. Only 21% reported that their flight departments offer training on fatigue issues. Almost three quarters (74%) described fatigue as a "moderate" or "serious" concern, and a majority (61%) characterized it as a common occurrence. Most (85%) identified fatigue as a "moderate" or "serious" safety issue.

[112] Rosekind, M. R., Gander, P. H., Miller, D. L., Gregory, K. B., Smith, R. M., Weldon, K. J., Co, E. L., McNally, K. L., and Lebacqz, J. V. (1994). "Fatigue in operational settings: examples from the aviation environment." Human Factors **36**(2): 327-338.

> The need for 24-h operations creates nonstandard and altered work schedules that can lead to cumulative sleep loss and circadian disruption. These factors can lead

to fatigue and sleepiness and affect performance and productivity on the job. The approach, research, and results of the NASA Ames Fatigue Countermeasures Program are described to illustrate one attempt to address these issues in the aviation environment. The scientific and operational relevance of these factors is discussed, and provocative issues for future research are presented.

[113] Rosekind, M. R., Gregory, K. B., Co, E. L., Miller, D. L., and Dinges, D. F. (2000). Crew factors in flight operations XII: A survey of sleep quantity and quality in on-board crew rest facilities. NASA Ames Research Center, NASA/TM-2000-209611, Moffett Field, CA.

Many aircraft operated on long-haul commercial airline flights are equipped with on-board crew rest facilities, or bunks, to allow crewmembers to rest during the flight. The primary objectives of this study were to gather data on how the bunks were used, the quantity and quality of sleep obtained by flight crewmembers in the facilities, and the factors that affected their sleep. A retrospective survey comprising 54 questions of varied format addressed demographics, home sleep habits, and bunk sleep habits. Crewmembers from three airlines with long-haul fleets carrying augmented crew consisting of B747-100/200, B747-400, and MD-11 aircraft equipped with bunks returned a total of 1404 completed surveys (a 37% response rate). Crewmembers from the three carriers were comparable demographically, although one carrier had older, more experienced flight crewmembers. Each group, on average, rated themselves as "good" sleepers at home, and all groups obtained about the same average amount of sleep each night. Most were able to sleep in the bunks, and about two thirds indicated that these rest opportunities benefited their subsequent flight deck alertness and performance. Comfort, environment, and physiology (e.g., being ready for sleep) were identified as factors that most promoted sleep. Factors cited as interfering with sleep included random noise, thoughts, heat, and the need to use the bathroom. These factors, in turn, suggest potential improvements to bunk facilities and their use. Ratings of the three aircraft types suggested differences among facilities. Bunks in the MD-11 were rated significantly better than either of the B747 types, and the B747-400 bunks received better rating than did the older, B747-100/200 facilities.

[114] Rosenberg, E. and Caine, Y. (2001). "Survey of Israeli Air Force line commander support for fatigue prevention initiatives." Aviat Space Environ Med **72**: 352-356.

The study examines the IAF line commander support for a variety of fatigue prevention initiatives. The survey questionnaire included questions regarding primary to tertiary fatigue prevention initiatives. The most popular primary prevention initiative (87% support) was the requirement for the reserve pilots to arrive at the squadron at least 3-h before night flights. The chief (88% support) secondary countermeasure was the utilization of stimulants such as caffeine or amphetamines to sustain alertness. The mostly used tertiary initiative (75% support) was the suggestion that squadrons debrief the incidence of aviator fatigue, as well as their success in the area of time-management when debrief in high tempo exercises and operational missions. The results showed that commanders differentially supported a wide range of fatigue countermeasures. Use of stimulants achieved the broadest support.

[115] Russo, M. B., Escolas, S., Santiago, S., Thomas, M. L., Sing, H. C., Thorne, D. R., Holland, D., Johnson, D. E., Redmond, D. P., and Hall, S. W. (2002). "Visual neglect in sleep deprived Air Force pilots in a simulated 12-hour flight." Sleep **25**(Abstract Supplement): A88.

The study examines sleep deprivation effect on visual awareness. Five USAF pilots, from whom two were instructors, participated in an Air Re-fueling Partial Task Trainer (ARPTT - C141 cargo jet) simulator. Results revealed significant response omissions were evident in three pilots (not the instructors) after 21.5-h of sleep deprivation. The instructors did not show any significant changes, possibly because of their increased familiarity with the simulator.

[116] Russo, M. B., Kendall, A. P., Johnson, D. E., Sing, H. C., Thorne, D. R., Escolas, S. M., Santiago, S., Holland, D. A., Hall, S. W., and Redmond, D. P. (2005). "Visual Perception, Psychomotor Performance, and Complex Motor Performance During an Overnight Air Refueling Simulated Flight." Aviat Space Environ Med **76**(7, Section II): C92-103.

Visual perception task, complex motor flight task, and psychomotor vigilance task performances were evaluated in U.S. Air Force pilots navigating a high-fidelity fixed wing jet simulator over 26.5 h of continuous wakefulness. Eight military pilots on flight status performed the primary task of flying a simulated 12.5-h overnight mission in an Air Refueling Part Task Trainer (ARPTT). Response omission to presentation of single- and double-light stimuli displayed in random sequence across the cockpit instrument panel was the metric used to assess choice visual perception task (CVPT) performance. Deviation from an established azimuth heading in the ARPTT during the CVPT was the flight metric used to assess complex motor performance. Speed, lapse, false start, and anticipation were the metrics used to assess psychomotor vigilance task (PVT) performance during crew rest periods. Results showed that significant visual perceptual, complex motor, and psychomotor vigilance (speed and lapse) impairments occurred at 19 h awake in the eight-subject group. CVPT response omissions significantly correlated with ARPTT azimuth deviations at r=0.97, and with PVT speed at r=-0.92 and lapses at r=0.90. ARPTT azimuth deviations significantly correlated with PVT speed at r=-0.92 and lapses at r=0.91. Acute sleep deprivation degrades visual perceptual, complex motor, and simple motor performance. Complex motor impairments strongly correlate with visual perceptual impairments. This research provides support for the use of visual perceptual measures as surrogates of complex motor performance in operational situations where the primary cognitive inputs are through the visual system.

[117] Russo, M. B., Sing, H., Kendall, A. P., Johnson, D. E., Santiago, S., Escolas, S., Holland, D., Thorne, D., Hall, S. W., Redmond, D. P., and Thomas, M. L. (2005). Visual perception, flight performance, and reaction time impairments in military pilots during 26 hours of continuous wake: Implications for automated workload control systems as fatigue management tools. Strategies to maintain combat readiness during extended deployments - A human systems approach. Neuilly-sur-Seine, France, RTO**:** 27-1 - 2716.

> Performance data from a visual perception task, complex motor flight task, and psychomotor vigilance task were evaluated in U.S. Air Force Pilots navigating a high-fidelity fixed-wing jet simulator over 26.5 hours of continuous wakefulness. Eight military pilots on flight status performed the primary task of flying a simulated 12.5-hour overnight mission in an Air Refueling Part Task Trainer (ARPTT). Response omission to presentation of single- and double-light stimuli displayed in random sequence across the cockpit instrument panel was the metric used to assess Choice Visual Perception Task (CVPT) performance. Deviation from an established azimuth heading in the ARPTT during the CVPT was the flight metric used to assess complex motor performance. Speed, lapse, false start, and anticipation were the metrics used to assess Psychomotor Vigilance Task (PVT) performance during crew rest periods. Results show that acute sleep deprivation degrades visual perceptual, complex motor, and simple motor performance. Significant visual perceptual, complex motor, and psychomotor vigilance (speed and lapse) impairments occurred at 19 hours awake in the 8-subject group. CVPT response omissions significantly correlated with ARPTT azimuth deviations at r = 0.97, and with PVT speed at r = -0.92 and lapses at r =0.90. ARPTT azimuth deviations significantly correlated with PVT speed at r = -0.92 and lapses at r = 0.91. Complex motor impairments in this task environment strongly correlate with visual perceptual impairments. This research provides support for the use of visual perceptual measures as surrogates of complex motor performance in operational situations where the primary cognitive inputs are through the visual system. This research supports the general notion that assessing visual system processes might be a component of cognitive monitoring systems that could potentially be applied to automated workload reduction systems.

[118] Russo, M. B., Sing, H., Santiago, S., Kendall, A. P., Johnson, D. E., Thorne, D., Escolas, S., Holland, D., Hall, S. W., and Redmond, D. P. (2004). "Visual neglect: occurrence and patterns in pilots in a simulated overnight flight." Aviat Space Environ Med **75**(4, Section I): 323-32.

> Visual neglect is the unconscious inability to recognize or acknowledge some visual information in the presence of a structurally intact visual system, and was hypothesized to occur with less than 24 h of continuous wakefulness. Visual perception was evaluated in military pilots during a simulated overnight flight to explore for the possible occurrence of visual neglect. Methods: There were eight military pilots (male, 31–52 yr of age, mean 37 yr) on flight status who were recruited to perform the primary task of flying a simulated 12.5 h overnight mission after a day of continuous wakefulness and the secondary task of responding to repeated 20 min presentations of single- and double-light stimuli

displayed in random sequence at 15° intervals across the cockpit instrument panel. In addition to the visual performance task, simulator shutdowns occurring when the tolerances of the simulator were exceeded were measured and simple reaction time on the psychomotor vigilance task was assessed. Total continuous wakefulness was 26.5 h. Combined performance on the visual perception task showed response omissions increasing at 19 h of continuous wakefulness. Patterns included omissions at all stimulus locations, of primarily peripherally located stimuli, and of one of two simultaneously presented stimuli. Simulator shutdowns began at 21.5 h of continuous wakefulness. Correlation of visual task response omissions with simulator shutdowns was $r=0.95$, $p<0.0001$. Significant neglect of visual stimuli occurred in pilots beginning at 19 h of continuous wakefulness in a simulated overnight fixed wing aircraft flight, preceded simulator shutdowns, and correlated at 0.95 with simulator shutdowns.

[119] Samel, A., Vejvoda, M., and Maass, H. (2004). "Sleep deficit and stress hormones in helicopter pilots on 7-day duty for emergency medical services." Aviat Space Environ Med **75**(11): 935-40.

Helicopter-based emergency medical services in Germany operate from sunrise to sunset, requiring up to 15.5 h of continuous duty during the summer months for pilots, who work for seven consecutive days. Because of concerns regarding the safety of this procedure with respect to pilot fatigue and stress, the German Ministry of Transport asked our laboratory to investigate the risks involved. There were 13 pilots (mean age 38 yr) who were studied in the summer months for 2 d before, 7 d during, and 2 d after their duty cycle. Measured variables included sleep duration and quality, subjective fatigue, and heart rate, as well as 24-h excretion levels of stress hormones. Results showed that during actual helicopter operations, maximum heart rates did not exceed 120 bpm. Over the 7-d duty period, mean sleep duration decreased from 7.8 h to 6 h or less, resulting in a cumulative sleep loss of about 15 h. Mean levels of excreted adrenalin, noradrenalin, and cortisol increased significantly by 50 to 80%; cortisol and noradrenalin excretion also remained elevated for the two post-duty days. Although the actual flights did not cause critical physiological responses, the acute and accumulated sleep deficit led to incomplete recuperation between duty hours and induced elevated stress indicators. It was, therefore, recommended that the duty cycle be amended as follows: 1) enforce a 10-h rest period and at least an 8-h sleep opportunity per day; 2) modify the duty period to allow no more than 3 consecutive rest periods of reduced sleep opportunities (8.5 h); and 3) follow duty with several days that offer unrestricted sleep opportunities.

[120] Sanquist, T. F., Raby, M., Forsythe, A., and Carvalhais, A. B. (1997). "Work hours, sleep patterns and fatigue among merchant marine personnel." Journal of Sleep Research **6**: 245-251.

A field study of work and sleep patterns among commercial merchant marine personnel is reported. Data collected over a 10-30-d period from 141 subjects aboard eight ships included information concerning work-rest schedules, sleep timing, alertness on the job and critical fatigue. The data indicate that watchstanders on the 4-on, 8-off schedule show considerable disruption in their sleep. The average sleep duration for all mariners is 6.6 h; watchstanders obtain their sleep in fragmented periods that are frequently less than 5 h in duration. Analysis of critical fatigue shows an incidence of 1 - 24% across personnel and measures. Of particular concern are the watchstanders on the 04.00-08.00 schedule, who sleep less than 4 h per 24-h period 22% of the time. Potential countermeasures, including changes in scheduling and staffing are proposed.

[121] Sanquist, T. F., Raby, M., Maloney, A. L., and Carvalhais, A. B. (1996). Fatigue and alertness in merchant marine personnel: a field study of work and sleep patterns. Department of Transportation, U.S. Coast Guard, Marine Safety and Environmental Protection, CG-D-06-97, Washington, D.C.

The study tries to identify 1) the nature and extent of sleep disruption-induced fatigue in the commercial maritime industry, and 2) the impact of watch duration on personnel fatigue. One hundred forty-one mariners from eight commercial ships (6 tankers and 2 freighters) provided data regarding their work and sleep patterns, as well as a variety of other data pertinent to fatigue. The results show that there is a fatigue problem in the U.S. maritime industry. The incidence of critical fatigue indicators such as severely restricted sleep durations per 24-h 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.

[122] Sawyer, T. L. (2004). The effects of reversing sleep-wake cycles on mood states, sleep, and fatigue on the crew of the USS JOHN C. STENNIS. Operations Research, Naval Postgraduate School, Monterey, CA, 127.

The study investigates the effects of reversing sleep-wake cycles on mood, sleep, and fatigue of the crewmembers and Air Wing 9 of the USS JOHN C. STENNIS (CVN-74). The effects of reversing sleep-wake cycle on mood of the crewmembers were analyzed by assessing a repeated administration of the Profile of Mood States (POMS). Mood states were monitored at three time points associated with the current work schedule (night shift vs. day shift) of the crewmembers. 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. Given these findings, this area of research warrants further exploration. There is a significant need to educate military personnel of the effects of sleep deprivation and shiftwork on their job performance and individual health and safety.

[123] Schultz, D. and Miller, J. (2004). Fatigue and use of Go/No Go pills in F-16 pilots subjected to extraordinary long combat sorties. Unites States Air Force Research Laboratory, Human Effectiveness Directorate, AFRLS-HE-BR-TR-2004-0014, Brooks City-Base, TX.

> The study assess the effect of GO/NOGO pills (USAF terms for stimulants/aids) to 19 F-16 pilots (almost an entire deployed squadron). The pilots were deployed and subjected to combat sorties, often longer than 8-h in duration, in support of Operations Southern Watch and Enduring Freedom. The mean flight time over the 3-month period was 140-h. Fifteen of the pilots reported the use of zolpidem. Sleep aids were reported as being effective, but pilots had varied perceptions about their relative effectiveness. There was a significant negative trend between sleep aid frequency and pilot age. During long sorties (longer than 8 hours) sixteen pilots used dextroamphetamine, and all pilots used it when returning to base and/or prior to landing. Overall, alertness aid was perceived as being effective. Seven of the 16 dextroamphetamine users reported difficulty sleeping after their use. At an organizational level, pilot schedulers were unaware of how to plan flights schedules to optimize fatigue issues.

[124] Shappell, S. A. and Neri, D. F. (1993). "Effect of combat on aircrew subjective readiness during operations Desert Shield and Desert Storm." The Journal of Aviation Psychology **3**(3): 231-252.

> For 4 consecutive weeks during Operations Desert Shield and Desert Storm, 18 A-6 and 18 F-14 aircrew onboard USS America provided detailed daily activity data and subjective readiness reports. Results show that operational tasking changed significantly as squadrons transitioned from Desert Shield (peace time) to Desert Storm (combat). During the first operation the majority of flights occurred during a normal work day, whereas in the latter operation the type and timing of missions changed (many missions occurred during night time). Multiple regression analysis indicated that aircrew combat readiness was predicted by flight duration, time of day that a flight occurred, number and order of flights in a day, and the amount of sleep obtained 12-h before flying.

[125] Shappell, S. A., Neri, D. F., and DeJohn, C. A. (1992). "Simulated sustained flight operations and performance, part 2: effects of dextro-methamphetamine." Military Psychology **4**(4): 267-287.

> Subjects (N=25) were used to examine the ability of dextro-methamphetamine to ameliorate the detrimental effects of a simulated SUSOP. Subjective fatigue and cognitive performance were evaluated through subjective questionnaires. The aircrew appeared to shift from a conservative to a more risky response strategy as the simulated SUSOP progressed. Administration of d-methamphetamine reduced subjective fatigue, improved performance, and partially lessened the apparent risky behavior.

[126] Sharkey, K. M., Fogg, L. F., and Eastman, C. I. (2001). "Effects of melatonin administration on daytime sleep after simulated night shift work." Journal of Sleep Research **10**: 181-192.

> This study was 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. The study utilized a placebo-controlled, double-blind, cross-over design. Subjects (n=21) participated in two 6-day laboratory sessions. Each session included one adaptation night, two baseline nights, two consecutive 8-h night shifts followed by 8-h daytime sleep episodes and one recovery night. 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. Sleep was recorded using polysomnography. Sleepiness, performance, and mood during the night shifts were evaluated using the multiple sleep latency test (MSLT) and a computerized neurobehavioral testing battery. 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 on the MSLT, or performance and mood during the night shift. There were no hangover effects from melatonin administration. These findings suggest that although melatonin can help night workers obtain more sleep during the day, they are still likely to face difficulties working at night because of circadian rhythm misalignment. The possibility of tolerance to the sleep-promoting effects of melatonin across more than 1 day needs further investigation.

[127] Shen, J., Botly, L. C. P., Chung, S. A., Gibbs, A. L., Sabanadzovic, S., and Shapiro, C. L. (2006). "Fatigue and shift work." Journal of Sleep Research **15**(1): 1-5.

> 489 workers from a major Ontario employer completed a series of subjective, self-report questionnaires, including the Fatigue Severity Scale (FSS) and the Epworth Sleepiness Scale. Workers were separated into four groups based on the frequency with which they are engaged in shift work. The frequency of shift work was found to have a significant effect on subjective fatigue, but not on subjective sleepiness. Compared with the subjects who never had a shift schedule, those who worked in a shift for 3 days or more had significantly higher mean score of the FSS. Low correlation was found between workers' subjective fatigue and sleepiness scores, providing further support for the concept of fatigue and sleepiness as distinct and independent phenomena.

[128] Simons, M. and Valk, P. J. L. (1999). Sleep and alertness management during military operations: review and plan action. Aeromedical Institute, 1999-K5, Soesterberg, Netherlands.

> The review focuses on fatigue and sleepiness related issues in the operational environment. It addresses issues such as the use of strategic naps, hypnotics, stimulants, and chronobiotic treatment. Finally, a work program is drawn up, aimed at developing guidelines to optimize performance during sustained intensive operations.

[129] Skiller, B., Booth, C., Coad, R., and Forbes-Ewan, C. (2005). Assessment of Nutritional Status and Fatigue among Army Recruits during the Army Common Recruit Training Course Part B: Psychological and Health Aspects. Defence Science and Technology Organisation, Australian Department of Defence, DSTO-RR-0300, Fishermans Bend, Victoria, Australia.

DSTO researchers conducted a nutritional survey of all food available to recruits at ARTC, and recruits from two platoons self-recorded their quality of sleep, symptoms of fatigue and ill health, mood state, level of coping ability and dietary intake. Fasting blood measures of immune status, hormones (serum free testosterone to cortisol ratio), inflammation, and iron status were measured on three occasions. Mean total energy expenditure was estimated by the "factorial method." Components of physical fitness (aerobic endurance, strength and muscular endurance, and explosive power) were measured on three occasions. Height was measured initially and well-hydrated weight measured on three occasions. The study was conducted in two phases; the recommendations of the first phase, which specifically addressed dietary issues, were presented in Part A of this report. The second phase, which investigated the proposition that recruits might display symptoms of overtraining, is addressed in this report. We conclude that there was some evidence for recruits being overtrained. The combined demands of the 45-day Army Recruit Common Training course, resulted in a significant prevalence of overtraining symptoms such as fatigue, sleep disturbance, immune suppression, reduced iron status, high rate of minor injuries and hormonal changes. However, recruits were not pushed so hard that physical performance deteriorated greatly. Accumulated sleep deprivation might be a major contributor to the adverse hormonal changes.

[130] Spinweber, C. L., and Johnson, L. C. (1983). Psychopharmacological Techniques for Optimizing Human Performance. Naval Health Research Center, 83-11, San Diego, CA.

The study describes a methodology for evaluation of sleeping aids for military use. In laboratory study of triazolobenzodiazepine triazolam 0.5 mg, sleep latency was reduced and morning performance was unimpaired, although a clear performance decrement was present up to 5 hours post-administration. Triazolam also produced anterograde amnesia and elevated auditory threshold for arousal from sleep. In operational use, triazolam could be effectively administered when rest periods of 8-h duration are scheduled. The dietary amino acid l-tryptophan 4 g was effective in reducing daytime sleep latency in normal sleepers, suggesting its usefulness in alleviating sleep disturbances from jet-lag and altered work-rest schedules.

[131] Steele, T. P., Kobus, D. A., Banta, G. R., and Armstrong, C. G. (1989). Sleep problems, health symptoms, and tension/anxiety and fatigue during cruising in a moderately high heat/humidity naval environment. Naval Health Research Center, NHRC Report No. 89-21, San Diego, CA.

> The study quantifies cognitive, behavioral, and physiological responses to SUSOPS in a hostile theater of operations. Officers and enlisted personnel (n=562) were surveyed aboard nine U.S. Navy combatants during a 2-month period in the Persian Gulf. During this period there was no hostile action. Thirty three watchstanders from Combat Information Center, Engineering and Topside were used in a four-day repeated measures sub-study. Almost 25% reported problems with falling asleep, poor quality sleep, sleep inertia, and sleeping on the job. Nearly 37% indicated severe fatigue. Although the most frequently reported symptoms were mental fatigue, heat distress, and muscle fatigue, their severity was minor.

[132] Stoner, J. D. (1996). "Aircrew fatigue monitoring during sustained flight operations from Souda Bay, Crete, Greece." Aviat Space Environ Med **67**(9): 863-866.

> The study evaluates aircrew fatigue by using 42 U.S. Navy EP-3E aircrew members flying reconnaissance missions from Souda Bay, Crete, Greece. Aircrews were monitored for signs of fatigue at the standard 120-h/ 30-d threshold. As suspected, no physiologic parameter indicated early fatigue. However, some aircrew demonstrated small changes in measured visual phorias as compared to prior evaluations. When the crews exceeded the 120-h flight limit, completed fatigue questionnaires (n=69). Crews reported their state of fatigue as manageable, their potential for increasing tempo good, and their crew ability to perform adequate. The study concludes that by incorporating previously reported recommendations for fatigue surveillance, the Souda Bay experience is an example of successful fatigue monitoring in aircrews who accumulate flight time beyond standard restrictions.

[133] Symons, J. D., VanHelder, T., and Myles, W. S. (1988). "Physical performance and physiological responses following 60 hours of sleep deprivation." Med Sci Sports Exerc **20**(4): 374-80.

> The effect of 60 h of sleep deprivation (SD) upon physical performance and physiological responses to exercise was examined in 11 male subjects. The experiment consisted of two conditions separated by at least 10 d. In the experimental condition (E) subjects remained awake for 60 h and in the control condition (C) the same subjects had 7 h of sleep per night. In both conditions subjects reported to the laboratory on the evening prior to d 1 and slept for 7 h. Physical performance testing was carried out on d 1 and again on d 3 after either two nights of sleep or two nights of SD. Results obtained on d 3 are expressed relative to d 1, the control day. Maximal isometric and isokinetic muscular strength and endurance of selected upper and lower body muscle groups, performance of the Wingate Anaerobic Power Test, simple reaction time, the blood lactate response to cycle exercise at 70% VO2max, and most of the cardiovascular and respiratory responses to treadmill running at 70% and 80%

VO2max, were not significantly altered as a result of SD. These results suggest that sleep loss of up to 60 h will not impair the capability for physical work, a finding of considerable importance in sustained military operations which frequently involve the combination of both physical and mental tasks.

[134] Takeyama, H., Itani, T., Tachi, N., Sakamura, O., Murata, K., Inoue, T., Takanishi, T., Suzumura, H., and Niwa, S. (2005). "Effects of shift schedules on fatigue and physiological functions among firefighters during night duty." Ergonomics **48**(1): 1-11.

To examine the effects of shift schedules on fatigue and physiological functions among firefighters a 17-day field study at a fire station was carried out. Eleven firefighters, who were engaged in firefighting emergency services, participated in this study. At the fire station, night duty (22:00 – 07:00) was divided into 5 periods (P1: 22:00 – 00:00; P2: 23:45 – 01:45; P3: 01:30 – 03:30; P4: 03:15 – 05:15; P5:0 5:00 – 07:00). The participants were assigned to one of these 5 periods and awakened to answer calls from the city's central information centre. They took naps in individual rooms during night duty, except when on night shift or when called out on an emergency. Subjective complaints of fatigue, critical flicker fusion frequencies, 3-choice reaction times, and oral temperature were measured before and after work and following breaks during their 24 working hours. Heart rate variability was also recorded to evaluate autonomic nerve activity. The results show that during P3 and P4, participants who had to wake up at midnight took shorter naps. The rates of subjective complaints regarding P3 and P4 tended to be higher than those for P1, P2, and P5. The ratios of the low frequency component of heart rate variability to the high frequency component during P4 were significantly lower than those during P5. It is assumed that such an irregular sleeping pattern causes many complaints of subjective fatigue, and adversely affects physiological functions. A night-duty shift schedule ensuring undisturbed naps should be considered.

[135] Tharion, W. J., Shukitt-Hale, B., and Lieberman, H. R. (2003). "Caffeine effects on marksmanship during high-stress military training with 72 hour sleep deprivation." Aviat Space Environ Med **74**(4): 309-14.

Marksmanship accuracy and sighting time were quantified with 62 male trainees during Navy SEAL Hell Week, which involves the combined stress of sleep loss, operational combat scenarios, and cold-wet environmental conditions. Caffeine was administered to minimize deficits due to sleep deprivation. Volunteers dry-fired a disabled rifle equipped with a laser-based marksmanship simulator system to measure shooting speed and accuracy. The target was a 2.3-cm diameter circle at a distance of 5 m, simulating a 46 cm target at a distance of 50 m. Marksmanship was assessed prior to training, and at 73 and 80 h into Hell Week. Volunteers were randomly assigned to 1 of 4 treatments: 100, 200, or 300 mg of caffeine or a placebo. Dosing occurred 72 h after training commenced. Results show that the combined effects of almost 73 h of total sleep deprivation and operational and environmental stress degraded all marksmanship accuracy measures ($p < 0.05$) as shown by the 37.5% increase in percent of targets missed, 38% increase in distance from center of mass of the target, and the 235% increase in shot group tightness. Sighting time increased by 53% or 3.1 s after 73 h of sleep deprivation ($p < 0.05$). Sighting time was significantly faster in sleep deprived individuals after taking 200 or 300 mg of caffeine compared with placebo or 100 mg of caffeine. No differences in accuracy measures between caffeine treatment groups were evident at any test period. CONCLUSION: During periods of sleep deprivation combined with other stressors, the use of 200 or 300 mg of caffeine enabled SEAL trainees to sight the target and pull the trigger faster without compromising shooting accuracy.

[136] Thompson, W. T., Lopez, N., Hickey, P., DaLuz, C., and Caldwell, J. L. (2006). Effects of shift work and sustained operations: Operator performance in remotely piloted aircraft (OP-REPAIR). United States Air Force, 311th Human Systems Wing, HSW-PE-BR-TR-2006-0001, Brooks City-Base, TX.

The study evaluates the objective impact of rotational shift work during a period of SUSOPS on fatigue, alertness, cognition, and piloting performance of UAV crews. Participants were 28 pilots, sensor operators, and intelligence personnel at Nellis AFB, Nevada directly involved in USAF MQ-1 Predator missions in support of Operations Enduring Freedom and Iraqi Freedom. Results show that a) 55% of the participants potentially met criteria for Shift Work Sleep Disorder, b) Decrements in mood, cognitive and piloting performance, and alertness were observed over the duration of a shift and were prevalent across all shifts and shift rotation schedules, c) The Ground Control Station task environment was associated with a moderate or greater level of subjective boredom, and d) flying time limitations appeared to have significant shortcomings as a safeguard against fatigue.

[137] Thompson, W. T., and Tvaryanas, A. P. (2006). A survey of fatigue in United States Air Force shift worker populations. USAF 311th Human Systems Wing, Performance Enhancement Directorate, HSW-PE-BR-TR-2006-0003, Brooks City-Base, TX.

The study qualitatively assess fatigue in four USAF shift worker population (172 personnel in total from a) unmanned aircraft system crewmembers, b) unmanned aircraft system maintenance personnel, c) manned aircraft crewmember, d) manned aircraft maintenance personnel), with shift work including irregular, rotational, or fixed shifts . Fatigue was not correlated with self-reported daily sleep and sleep quality. Fatigue, which was greater in the unmanned aircraft versus the manned aircraft, implied organizational work-related factors such as workload or manpower were underlying this observation. Crewmembers and maintenance personnel reported equal levels of fatigue. Shift workers were equally fatigued whether at home base or deployed in current military operations.

[138] Treadwell, T. A. (1997). The effects of sustained operations on female soldiers performance. Army Research Laboratory, Aberdeen Proving Ground, MD.

The study compares the effects of sustained operations of male and female soldiers in a field environment. The field study examined cognitive performance; subjective mood, fatigue, and environmental ratings; and physiological measurements. Participants were 26 soldiers (13 females and 13 males) from the 180th Transportation Battalion, at Ford Hood, Texas. Results show that, with the exceptions of oral temperature and logical reasoning, gender differences during sleep deprivation were not found, thus there would be a minimum impact on extended military operations involving women participants.

[139] Wesensten, N. J., Belenky, G. L., Thorne, D. R., Kautz, M. A., and Balkin, T. J. (2004). "Modafinil vs. caffeine: effects on fatigue during sleep deprivation." Aviat Space Environ Med **75**(6): 520-525.

The extent to which modafinil and caffeine reverse fatigue effects (defined as performance decrements with time on task) during total sleep deprivation was investigated. Methods: There were 50 healthy young adults who remained awake for 54.5 h (06:30 day 1 to 13:00 day 3). A 10-min vigilance test was administered bi-hourly from 08:00 day 1 until 22:00 day 2. At 23:55 day 2 (after 41.5 h awake), double-blind administration of one of five drug doses (placebo; modafinil 100, 200, or 400 mg; or caffeine 600 mg; n=10 per group) was followed by hourly testing from 00:00 through 12:00 day 3. Response speed (reciprocal of reaction time) across the 10-min task (by 1-min block) was analyzed prior to and after drug administration. Results: A fatigue effect (response speed degradation across the 10-min task) was exacerbated by sleep deprivation and circadian rhythmicity. Prior to the drug, this effect was maximal between 08:00 and 12:00 day 3 (24–28 h sleep deprivation). Modafinil 400 mg attenuated fatigue in a manner comparable to that seen with caffeine 600 mg; these effects were especially salient during the circadian nadir of performance (06:00 through 10:00); modafinil 200 mg also reversed fatigue, but for a shorter duration (3 min) than modafinil 400 mg (8 min) or caffeine 600 mg (6 min). Discussion and Conclusions: Time-on-task effects contributed to the performance degradation seen during sleep deprivation; effects which were reversed by caffeine and, at appropriate doses, by modafinil. Because the duration of efficacy for reversing time-on-task effects was shorter at lower drug dosages, the latter must be considered when determining the appropriate dose to use during sustained operations.

[140] Westcott, K. J. (2005). "Modafinil, sleep deprivation, and cognitive function in military and medical settings." Mil Med **170**(4): 333-5.

Military personnel of many professions, including health care workers, are routinely challenged with performing their duties during hours when the circadian rhythm is at its trough, namely, late night and early morning. Studies have shown that cognitive performance declines significantly during these hours. Although many pharmacologic agents have been studied in an attempt to find a safe medication to enhance alertness and cognitive function, no safe nonaddictive

options have been identified. Modafinil is a novel wakefulness-promoting agent that has been shown to improve cognitive performance and promote wakefulness among shift workers. This article reviews the studies on modafinil administration and cognitive performance as they relate to military operations and the provision of health care by sleep-deprived individuals.

[141] Whitmore, J., Doan, B., Heintz, T., Hurtle, W., Kisner, J., and Smith, J. (2004). The efficacy of modafinil as an operational fatigue countermeasure over several days of reduced sleep during a simulated escape and evasion scenario. Air Force Research Laboratory, Human Effectiveness Directorate, AFRL-HE-BR-TR-2004-0021, Brooks City-Base, TX.

The study assesses the operational efficacy of modafinil (100 mg and 200 mg every 8-h/ 300 mg or 600 mg per day) to maintain alertness ad performance levels over several days of sleep deprivation in field environments. There were twenty USAF Survival Training Specialists who participated in a simulated activity of aircrew escape and evasion scenarios during 65-h sleep deprivation field event. Results support the positive effects of modafinil to partially attenuate the performance decrements associated with fatigue (sleep loss and circadian variation).

[142] Whitmore, J., Hickey, P., Doan, B., Harrison, R., Kisner, J., Beltran, T., McQuade, J., Fischer, J., and Marks, F. (2006). A Double-Blind Placebo-Controlled Investigation of the Efficacy of Modafinil for Maintaining Alertness and Performance in Sustained Military Ground Operations. Air Force Research Laboratory, Human Effectiveness Directorate, AFRL-HE-BR-TR-2006-0005, Brooks City-Base, TX.

The study evaluates the effect of modafinil on performance maintenance capability through the administration of modafinil to 12 male participants (special tactics military personnel) in an 88-h sleep loss experiment. The results provide evidence that modafinil administration partially attenuates the performance decrement caused by sleep loss in field environments (although all measures used showed an increase with modafinil administration, only some of them were statistically significant). Furthermore, modafinil was found to have no adverse physiologic effects, to produce few side effects, and wide acceptance by the participants.

[143] Williams, D., Streeter, J., and Kelly, T. (1998). Fatigue in Naval Tactical Aviators. Naval Health Research Center, NHRC Report No. 98-20, San Diego, CA.

The study evaluates sleeping habits and problems of fatigue in two groups of tactical aviators. Surveys were distributed to Naval and Marine Corps aircrews (n=78) in the F/A-18 (n=32) and the F-14 communities (n=46). While the reported mean night sleep in weekdays was 7.15-h, average sleep when deployed or periods of high operational tempo was 5.85-h. Forty percent of aviators reported napping to supplement night sleep. Results show that aviators in the first group reported that their job performance is compromised by fatigue. Almost one third of the participants reported having fallen asleep in the cockpit at least once, with an average of three times in their careers.

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Abbreviations

ANAM - Automated Neuropsychological Assessment Metrics
ARCI - Addiction Research Center Inventory
ARPTT - Air Refueling Part Task Trainer
ARTC - Army Common Training Course
ATC - Air Traffic Controller
BUDS - Basic Underwater Demolition and Seal
C2 - Command and Control
C4ISR - Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CBT - Cadet Basic Training
CNS - Central Nervous System
CONOPS - Continuous Operations
CVPT - Choice Visual Perception Task
EEG - Electroencephalography
FSS - Fatigue Severity Scale
IAF - Israeli Air Force
IGT - Iowa Gambling Task
LHF - Long-haul Flights
MATB - Multi Attribute Test Battery
MQ - Mood Questionnaire
MLST - Multiple Sleep Latency Test
MWT - Maintenance of Wakefulness Test
NAMRL - Naval Aerospace Medical Research Laboratory
NHRC - Naval Health Research Center
NORAD - North American Aerospace Defense Command
NTC - National Training Center
ORVT - Observation and Reconnaissance Vigilance Task
PAB - Performance Assessment Battery
POMS - Profile of Mood States
PVT - Psychomotor Vigilance Test
RT - Reaction Time
SD - Sleep Deprivation
SHF - Short-haul Flights
SSS - Stanford Sleepiness Scale
SUSOPS - Sustained Operations
USCG - United States Coast Guard
UAV - Unmanned Aerial Vehicle
WAM - Wrist Activity Monitor
WMEC - Medium Endurance Cutter
WHEC - High Endurance Cutter
WRAIR - Walter Reed Army Institute of Research

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