The Efficacy of Naps as a Fatigue Countermeasure: A Meta-Analytic Integration

James E. Driskell, Florida Maxima Corporation, Winter Park, Florida, and **Brian Mullen,** Syracuse University, Syracuse, New York

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.

INTRODUCTION

I'm beyond the stage where I need a bed, or even to lie down.... My mind clicks on and off, as though attached to an electric switch with which some outside force is tampering. I try letting one eyelid close at a time while I prop the other open with my will. But the effort's too much. Sleep is winning. My whole body argues dully that nothing, nothing life can attain, is quite so desirable as sleep. My mind is losing resolution and control.

—Charles Lindbergh, 9 hr into his historic flight (Lindbergh, 1953, p. 233)

Concern with the negative effects of fatigue is paramount in aviation (Rosekind, Gander, et al., 1994), nuclear power (Baker, Olson, & Morisseau, 1994), mining (Duchon, Keran, & Smith, 1994), the military (Neville, Bisson, French, Boll, & Storm, 1994), health care (Veasey, Rosen, Barzansky, Rosen, & Owens, 2002), and other settings in which personnel must perform over extended periods. Sleep loss stemming from extended operations can lead to impaired performance, and fatigue has been implicated in accidents such as the grounding of the *Exxon Valdez* (National Transportation Safety Board, 1989), the 1995 New York City subway train collision (National Transportation Safety Board, 1996), and the American International Airways DC-8 aircraft accident at Guantanamo Bay, Cuba (National Transportation Safety Board, 1994). In industries in which the tolerance for error is low and the consequences for error are high, the problem of fatigue is of significant importance.

Because of the scope of this problem, a considerable amount of research has examined the effectiveness of various interventions that might reduce fatigue. These interventions, referred to as *fatigue countermeasures,* include naps (e.g., Bonnet & Arand, 1995), bright lights (e.g., Thessing, Anch, Muehlbach, Schweitzer, & Walsh, 1994), caffeine (e.g., National Research Council, 2001), and activity breaks (Neri et al., 2002). Although there is general agreement that naps may be a useful fatigue countermeasure, there is less consensus on how naps should be managed as an effective operational strategy. In a pioneering study on the effects of in-flight naps on aviation flight crews, Rosekind, Graeber, et al. (1994) found that naps benefited performance but had little impact on subjective ratings of

Address correspondence to James E. Driskell, Florida Maxima Corporation, 507 N. New York Ave., R-1, Winter Park, FL; james.driskell@rollins.edu. **HUMAN FACTORS,** Vol. 47, No. 2, Summer 2005, pp. 360–377.

alertness. Moreover, they raised questions they were not able to answer conclusively as to whether naps of longer or shorter duration may be more effective, over what postnap period the performance effects remain, and whether sleep inertia (the grogginess experienced after waking) is a significant concern. Several narrative reviews of the efficacy of naps as a fatigue countermeasure have been published (e.g., Bonnet, 1990; Caldwell, 1997; Dinges & Broughton, 1989; Gillberg, 1985; Rosekind et al., 1995). However, it is a difficult task, at the narrative level, to integrate the results of disparate empirical studies and derive specific guidelines for operational use. To address these questions, we conducted a meta-analysis of the efficacy of naps as a fatigue countermeasure.

THE EFFICACY OF NAPS AS A FATIGUE COUNTERMEASURE

A meta-analytic integration of the research literature on the efficacy of naps as a fatigue countermeasure can accomplish two primary objectives. First, it can provide a very specific and precise summary of the overall effects within this research domain. The collective wisdom seems to be that naps can reduce but not reverse the effects of sleep loss (e.g., Bonnet, 1990; Dinges & Broughton, 1989; Gillberg, 1985; Rosekind et al., 1995). However, to date, there has been no precise empirical specification of whether naps exert a strong, moderate, or weak effect in reducing the effects of fatigue. Therefore, one goal of the present effort was to specify the precise significance and magnitude of the efficacy of naps as a fatigue countermeasure.

A second goal of this analysis was to examine the extent to which the efficacy of naps increases or decreases as a function of certain theoretically relevant and practically important moderators. Researchers have noted that naps may be more or less effective depending on how they are implemented (e.g., Bonnet, 1991; Gillberg, 1985; Rosekind et al., 1995). Several specific questions regarding the efficacy of naps as a fatigue countermeasure can be derived from the narrative reviews cited previously, questions that can be subjected to empirical scrutiny with meta-analysis. This capacity for meta-analysis to account for systematic variability in effect sizes, and to render precise tests of the effects of theoretically relevant and practically important moderators, can be one of its greatest contributions to the understanding of a phenomenon (Mullen, Driskell, & Salas, 1998). These questions are addressed in the following.

The effects of naps on performance versus fatigue. Is there a difference between the effects of naps on performance and the effects of naps on feelings of fatigue? Johnson, Freeman, Spinweber, and Gomez (1988) reported that the largest correlation between measures of performance and measures of feelings of fatigue was a modest $r = .18$. This suggests that naps may exert an impact on one outcome measure (e.g., performance) but not necessarily exert an equivalent impact on another outcome measure (e.g., fatigue). Gillberg (1985, p. 86) went so far as to speculate that naps would exert a noticeable effect on fatigue even though performance might remain relatively unaffected. Thus another goal of this study was to examine the differential effects of naps on performance and on fatigue.

The effects of nap duration. Is there a significant effect of the duration of naps on the efficacy of naps? There is some controversy in the research literature regarding the effects of nap duration on nap efficacy. On one hand, some scholars (e.g., Gillberg, 1985, p. 85) have argued that the duration of a nap does not seem to be critical. On the other hand, some scholars (e.g., Bonnet, 1991, p. 313) have argued that the beneficial effects of naps vary as a direct linear function of nap duration. Thus another goal of this study was to examine the effects of nap duration on the efficacy of naps as a fatigue countermeasure.

The effect of postnap interval. Is there a significant effect of the postnap interval on the efficacy of naps? There seems to be a consensus that the postnap interval is important; however, the precise nature of the effect of the postnap interval remains open to speculation. Some scholars (e.g., Naitoh, Englund, & Ryman, 1983; Rosekind et al., 1995) have argued that the beneficial effects of a nap dissipate as the postnap interval increases, whereas other scholars (e.g., Bonnet, 1991) have argued that the beneficial effects of a nap can continue to provide benefits perhaps for as long as a 54-hr postnap interval. Thus another goal of this study was to examine the effects of postnap interval on the efficacy of naps as a fatigue countermeasure.

The effect of circadian rhythm. Is there a significant effect of circadian rhythm on the effectiveness of naps? As several authors have suggested (e.g., Bonnet, 1990; Gillberg, 1985), variation across studies in the effectiveness of naps on performance might be a function of natural variation in performance efficiency as a function of the time of day, reflecting the effects of circadian rhythm. Thus another goal of this study was to examine the effects of circadian rhythms on the efficacy of naps as a countermeasure.

The possibility of sleep inertia. Rosekind et al. (1995) and others have voiced concerns regarding conditions under which naps may compromise operator safety. *Sleep inertia* refers to a period of disorientation and performance decrement that may occur immediately upon waking from a nap. Although Rosekind, Graeber, et al. (1994) found no evidence of sleep inertia in their study of planned cockpit rests in flight operations, others have provided estimates of the effects of sleep inertia ranging from 15 min (Bertelson, 1979) to 20 min (Taub, 1979) to 35 min (Dinges, Orne, Evans, & Orne, 1981). Thus one goal of this study was to investigate the possibility of detrimental effects of sleep inertia.

A META-ANALYTIC INTEGRATION

Procedure

In general terms, every available study testing the effects of naps as a fatigue countermeasure was obtained, and the specific test or tests of the effects of naps were extracted. Using all of the standard literature search techniques, an exhaustive search was conducted for studies examining the effects of naps. Specifically, on-line computer searches (using MEDLINE, PsycINFO, and the Defense Technical Information Center's STINET) were conducted using the keywords *nap(-s, -ping), rest, sleep,* and *fatigue.* This computer search was supplemented by ancestry approach searches (examining the reference lists of retrieved studies), descendancy approach searches (locating subsequent studies that cited retrieved studies in *Science Citation Index* and *Social Science Citation Index*), and scanning the past 25 years of leading biomedical and behavioral research journals. (See Mullen, 1989, for a discussion of literature search techniques.) Studies that were available as of May 2004 were eligible for inclusion in this integration.

In order to be included in the present effort, a study had to provide one or more clear and unequivocal tests of the effects of naps as a fatigue countermeasure in a normal, nonclinical adult population. Specifically, participants had to be described as actually sleeping during the prescribed nap period, not merely resting. Studies had to provide sufficient information for the accurate reconstruction of a precise test of the effects of a nap of a specific duration on a measure of performance or fatigue at some specified time after the participants awoke from the nap. Typically, as accurately characterized by previous reviewers of this literature (Bonnet, 1990; Dinges, Orne, Whitehouse, & Orne, 1987), the performance or fatigue of individuals was compared with their own baseline performance prior to the extended operation. In other words, participants were tested at baseline, kept awake for a period of time, then allowed a nap, and then tested again. Thus all included studies employed within-subjects pretest-posttest designs.

A number of studies that have been cited in support of the efficacy of naps as a fatigue countermeasure were not included in the meta-analytic database, for the following reasons. Several studies provided insufficient data to allow the extraction of statistical tests of the effects of naps (e.g., Daiss, Bertelson, & Benjamin, 1986; DeValk, DeGroot, & Cluydts, 2003; Dinges et al., 1987; Gillberg, 1984; Hartley, 1974; Moses, Lubin, Naitoh, & Johnson, 1978; Naitoh & Angus, 1987; Schweitzer, Muehlbach, & Walsh, 1992; Webb, 1987). Thus any studies with reports that did not allow the reconstruction of a precise statistical test could not be included in the present effort. It should be noted that in an effort to obtain the most complete meta-analytic database, attempts were made via letter to contact the authors of those studies that provided incomplete or insufficient data for extraction of statistical tests. We requested information regarding 29 studies and were able to obtain additional statistical information on 3 additional studies, which were incorporated into the meta-analytic database.

Some studies often cited in discussions of the efficacy of naps (e.g., Caldwell et al., 1997) were actually duplicate reports of the same data that were reported in another study already included in the meta-analytic database (e.g., Caldwell et al., 1998). Some studies did not actually examine the effects of naps of specified duration over specified postnap intervals. For example, some studies simply reported the results of a questionnaire survey (e.g., Akerstedt & Torsvall, 1985; Chan, Phoon, Gan, & Ngui, 1989) in which participants reported the extent to which they did or did not nap, as well as the extent to which they did or did not feel or perform well. Similarly, some studies examined the effects of sleep deprivation or disruption but did not actually introduce controlled naps of specified duration (e.g., Bonnet, 1986; Lavie & Weler, 1989; Opstad, Ekanger, Nummestad, & Raabe, 1978). A few studies examined the effects of naps in participant samples consisting entirely of people who were habitual nappers (e.g., Taub, 1977, 1979, 1982), who have been shown to be more likely to be characterized by the presence of a physical illness, bipolar disorder, and idiopathic hypersomnia (Ohayaon & Zulley, 1999). None of these studies were included in the present effort.

A total of 12 studies examining the effects of naps as a fatigue countermeasure met the foregoing criteria for inclusion (Badia & Harsh, 1985; Bonnet & Arand, 1995; Bonnet, Gomez, Wirth, & Arand, 1995; Caldwell et al., 1998; Gillberg, Keckland, Axelsson, & Akerstedt, 1996; Hayashi, Ito, & Hori, 1999; Hayashi, Watanabe, & Hori, 1999; Horne & Reyner, 1996; Takahashi & Arito, 2000; Takahashi, Fukuda, & Arito, 1998; Tietzel & Lack, 2001; Tilley & Wilkinson, 1984). These 12 studies rendered a total of 178 separate tests of the effects of naps as a fatigue countermeasure, representing the responses of 270 participants.

The hypothesis tests extracted from each of the included studies are presented in Table 1. As indicated previously, typically the performance or fatigue of individuals was compared with their own baseline performance prior to the extended operation. Because periods of extended operation often tend to lead to deterioration in performance and feelings of alertness, it is not surprising that participants typically exhibited decrements in performance and feelings of alertness relative to their own baseline. Each hypothesis test was coded as having a positive direction of effect if the participants' postnap measures were higher than their own baseline. Each hypothesis test was coded as having a negative direction of effect if the participants' postnap measures were lower than their own baseline. Thus a positive direction of effect indicates that the nap reverses the effects of sleep loss, whereas a negative direction of effect indicates that there are still effects of sleep loss after the nap.

Because the interpretation of effect sizes is somewhat counterintuitive, it may be useful to elaborate this point. Within this body of studies, participants were tested at a baseline period, kept awake for a period of time, allowed a nap, and then tested again. Thus a negative effect size indicates that performance after napping remained lower than baseline levels (i.e., in this case, the effects of fatigue remained after napping relative to baseline performance levels). A positive effect size indicates that performance after napping exceeded baseline levels (i.e., in this case, napping reversed the effects of fatigue to a level exceeding baseline performance). An effect size that approximates zero indicates that the nap has resulted in a return of performance to baseline levels. In addition, we should note that participants in these studies were kept awake for varying numbers of hours in order to make them fatigued. On average, participants were awake for M = 11.82 hr before napping. It should be noted that the effectiveness of naps as a fatigue countermeasure was not influenced by the length of the prenap waking interval, for either fatigue ($r = -.103$, $Z = 0.885$, $p = .1880$) or performance ($r = +.005$, $Z = 0.056$, $p = .4778$).

Results

The studies in this research domain employed, on average, a sample of approximately $N = 23$ participants. All studies employed healthy young adults (average age approximately 20 years). The naps implemented in these studies ranged in duration from 10 min to 8 hr (average = 2.2 hr), and measurements were taken after a postnap interval ranging from immediately following the nap to 45.5 hr later (average = 8.7 hr). Performance tasks included a

Text continues on page 367.

TABLE 1: Studies Examining the Efficacy of Naps as a Fatigue Countermeasure

Study/Measure	Statistic (*df*)	*N*	DOE	Effect Size	Nap Duration	Postnap Interval	Time of Day
Badia & Harsh (1985)							
Logical (P)	*t*(9) = 0.54	10	–	−0.179	1.0	1.00	09:00
Probe (P)	*t*(9) = 1.10	10	–	−0.359	1.0	1.00	09:00
Matrix2 (P)	*t*(9) = 1.06	10	–	−0.346	1.0	1.00	09:00
Add/Sub (P)	*t*(9) = 0.04	10	+	+0.013	1.0	1.00	09:00
Wilkinson (P)	*t*(9) = 1.77	10	–	−0.560	1.0	1.00	09:00
Mast6 (P)	*t*(9) = 1.54	10	+	+0.493	1.0	1.00	09:00
Logical (P)	*t*(9) = 0.05	10	–	−0.017	2.0	1.00	10:00
Probe (P)	*t*(9) = 1.27	10	+	+0.412	2.0	1.00	10:00
Matrix2 (P)	*t*(9) = 0.17	10	–	−0.057	2.0	1.00	10:00
Add/Sub (P)	*t*(9) = 0.14	10	+	+0.047	2.0	1.00	10:00
Wilkinson (P)	*t*(9) = 1.50	10	–	−0.481	2.0	1.00	10:00
Mast6 (P)	*t*(9) = 1.54	10	+	+0.493	2.0	1.00	10:00
Logical (P)	*t*(9) = 3.95	10	+	+1.089	4.0	1.00	12:00
Probe (P)	*t*(9) = 2.52	10	+	+0.764	4.0	1.00	12:00
Matrix2 (P)	*t*(9) = 1.06	10	–	−0.346	4.0	1.00	12:00
Add/Sub (P)	*t*(9) = 1.35	10	+	+0.436	4.0	1.00	12:00
Wilkinson (P)	*t*(9) = 4.49	10	+	+1.193	4.0	1.00	12:00
Mast6 (P)	*t*(9) = 0.84	10	–	−0.276	4.0	1.00	12:00
Bonnet & Arand (1995)							
AddCorr (P)	*t*(99) = 0.576	12	+	+0.058	4.0	3.00	23:00
AddCorr (P)	*t*(99) = 0.485	12	–	−0.049	4.0	13.00	05:00
AddCorr (P)	*t*(99) = 1.742	12	–	−0.174	4.0	15.00	11:00
AddCorr (P)	*t*(99) = 2.605	12	–	−0.259	4.0	21.00	17:00
AddCorr (P)	*t*(99) = 1.116	12	+	+0.117	1.0	0.00	23:00
DSS (P)	*t*(238) = 3.274	12	+	+0.211	4.0	0.50	20:30
DSS (P)	*t*(238) = 2.391	12	+	+0.154	4.0	3.00	23:00
DSS (P)	*t*(238) = 1.594	12	+	+0.103	4.0	7.00	03:00
DSS (P)	*t*(238) = 2.154	12	+	+0.259	4.0	9.00	05:00
DSS (P)	*t*(238) = 0.517	12	+	+0.034	4.0	13.00	09:00
DSS (P)	*t*(238) = 0.000	12	+	+0.000	4.0	14.50	10:30
DSS (P)	*t*(238) = 0.280	12	–	−0.018	4.0	18.50	14:30
DSS (P)	*t*(238) = 0.043	12	–	−0.003	4.0	20.50	16:30
DSS (P)	*t*(238) = 0.323	12	–	−0.021	4.0	24.50	20:30
DSS (P)	*t*(238) = 0.862	12	+	+0.056	1.0	0.00	23:00
Bonnet et al. (1995)							
Vigilance (P)	*t*(699) = 0.817	60	+	+0.031	2.62	3.50	23:30
Vigilance (P)	*t*(699) = 0.245	60	–	−0.009	2.62	9.50	05:30
Vigilance (P)	*t*(699) = 1.143	60	–	−0.043	2.62	15.50	11:30
Vigilance (P)	*t*(699) = 0.572	60	–	−0.022	2.62	21.50	17:30
Vigilance (P)	*t*(699) = 2.205	60	–	−0.083	2.62	27.50	23:30
Vigilance (P)	*t*(699) = 5.105	60	–	−0.192	2.62	33.50	05:30
Vigilance (P)	*t*(699) = 4.369	60	–	−0.165	2.62	39.50	11:30
Vigilance (P)	*t*(699) = 2.001	60	–	−0.076	2.62	45.50	17:30
Vigilance (P)	*t*(699) = 0.568	24	+	+0.021	8.00	3.50	23:30
Vigilance (P)	*t*(699) = 1.214	24	+	+0.046	8.00	9.50	05:30
Vigilance (P)	*t*(699) = 0.749	24	+	+0.028	8.00	15.50	11:30
Vigilance (P)	*t*(699) = 0.232	24	+	+0.009	8.00	21.50	17:30
Vigilance (P)	*t*(699) = 0.103	24	+	+0.004	8.00	27.50	23:30
Vigilance (P)	*t*(699) = 1.782	24	–	−0.067	8.00	33.50	05:30
Vigilance (P)	*t*(699) = 2.557	24	–	−0.097	8.00	39.50	11:30
Vigilance (P)	*t*(699) = 2.144	24	–	−0.081	8.00	45.50	17:30
POMS (F)	*t*(564) = 0.263	60	+	+0.011	2.62	3.50	23:30
POMS (F)	*t*(564) = 2.587	60	–	−0.109	2.62	9.50	05:30

TABLE 1 (continued)

Study/Measure	Statistic (*df*)	*N*	DOE	Effect Size	Nap Duration	Postnap Interval	Time of Day
POMS (F)	$t(564) = 4.279$	60	–	−0.179	2.62	15.50	11:30
POMS (F)	$t(564) = 3.890$	60	–	−0.163	2.62	21.50	17:30
POMS (F)	$t(564) = 4.863$	60	–	−0.203	2.62	27.50	23:30
POMS (F)	$t(564) = 7.128$	60	–	−0.296	2.62	33.50	05:30
POMS (F)	$t(564) = 7.907$	60	–	−0.327	2.62	39.50	11:30
POMS (F)	$t(564) = 6.934$	60	–	−0.288	2.62	45.50	17:30
POMS (F)	$t(564) = 0.209$	24	+	+0.009	8.00	3.50	23:30
POMS (F)	$t(564) = 0.492$	24	–	−0.021	8.00	9.50	05:30
POMS (F)	$t(564) = 1.476$	24	–	−0.062	8.00	15.50	11:30
POMS (F)	$t(564) = 1.925$	24	–	−0.081	8.00	21.50	17:30
POMS (F)	$t(564) = 2.214$	24	–	−0.093	8.00	27.50	23:30
POMS (F)	$t(564) = 3.856$	24	–	−0.162	8.00	33.50	05:30
POMS (F)	$t(564) = 3.567$	24	–	−0.150	8.00	39.50	11:30
POMS (F)	$t(564) = 3.610$	24	–	−0.151	8.00	45.50	17:30
Caldwell et al. (1998)							
Errors (P)	$t(102) = 3.933$	18	–	−0.380	2.00	10.17	09:10
Errors (P)	$t(102) = 6.802$	18	–	−0.631	2.00	14.17	13:10
Errors (P)	$t(102) = 6.517$	18	–	−0.607	2.00	18.17	17:10
VAS (F)	$t(561) = 1.503$	18	–	−0.063	2.00	10.00	09:00
VAS (F)	$t(561) = 1.629$	18	–	−0.069	2.00	11.00	10:00
VAS (F)	$t(561) = 1.004$	18	–	−0.042	2.00	12.00	11:00
VAS (F)	$t(561) = 0.504$	18	+	+0.021	2.00	13.00	12:00
VAS (F)	$t(561) = 1.508$	18	–	−0.064	2.00	14.00	13:00
VAS (F)	$t(561) = 1.629$	18	–	−0.069	2.00	15.00	14:00
VAS (F)	$t(561) = 1.125$	18	–	−0.047	2.00	16.00	15:00
VAS (F)	$t(561) = 0.000$	18	+	+0.000	2.00	17.00	16:00
VAS (F)	$t(561) = 1.004$	18	–	−0.042	2.00	18.00	17:00
VAS (F)	$t(561) = 0.000$	18	+	+0.000	2.00	19.00	18:00
VAS (F)	$t(561) = 1.503$	18	–	−0.063	2.00	20.00	19:00
VAS (F)	$t(561) = 1.887$	18	+	+0.080	2.00	21.00	20:00
Gillberg et al. (1996)							
Hits (P)	$t(28) = 3.234$	8	+	+0.578	0.50	0.75	12:00
Hits (P)	$t(28) = 1.197$	8	+	+0.224	0.50	3.75	13:00
KSS (F)	$t(14) = 1.817$	8	+	+0.468	0.50	2.25	13:50
Hayashi, Ito et al. (1999)							
Logical (P)	$t(54) = 1.784$	10	+	+0.240	0.33	0.33	13:00
Logical (P)	$t(54) = 0.855$	10	+	+0.116	0.33	1.33	14:00
Logical (P)	$t(54) = 0.332$	10	–	−0.045	0.33	2.33	15:00
Logical (P)	$t(54) = 1.765$	10	–	−0.238	0.33	3.33	16:00
Logical (P)	$t(54) = 1.735$	10	+	+0.234	0.33	4.33	17:00
Calc (P)	$t(54) = 0.627$	10	+	+0.085	0.33	0.33	13:00
Calc (P)	$t(54) = 0.886$	10	–	−0.120	0.33	1.33	14:00
Calc (P)	$t(54) = 0.558$	10	+	+0.076	0.33	2.33	15:00
Calc (P)	$t(54) = 0.286$	10	+	+0.039	0.33	3.33	16:00
Calc (P)	$t(54) = 0.241$	10	–	−0.033	0.33	4.33	17:00
Visual Det (P)	$t(54) = 1.247$	10	+	+0.169	0.33	0.33	13:00
Visual Det (P)	$t(54) = 1.145$	10	–	−0.155	0.33	1.33	14:00
Visual Det (P)	$t(54) = 0.079$	10	+	+0.011	0.33	2.33	15:00
Visual Det (P)	$t(54) = 1.319$	10	–	−0.179	0.33	3.33	16:00
Visual Det (P)	$t(54) = 0.778$	10	+	+0.106	0.33	4.33	17:00
Aud Vigil (P)	$t(54) = 1.082$	10	+	+0.147	0.33	0.33	13:00
Aud Vigil (P)	$t(54) = 0.431$	10	+	+0.059	0.33	1.33	14:00
Aud Vigil (P)	$t(54) = 0.294$	10	–	−0.040	0.33	2.33	15:00
Aud Vigil (P)	$t(54) = 1.325$	10	–	−0.179	0.33	3.33	16:00

TABLE 1 (continued)

Study/Measure	Statistic (*df*)	*N*	DOE	Effect Size	Nap Duration	Postnap Interval	Time of Day
Aud Vigil (P)	*t*(54) = 0.125	10	+	+0.017	0.33	4.33	17:00
Sleepiness (F)	*t*(54) = 2.534	10	+	+0.338	0.33	0.33	13:00
Sleepiness (F)	*t*(54) = 1.164	10	+	+0.158	0.33	1.33	14:00
Sleepiness (F)	*t*(54) = 0.137	10	–	–0.019	0.33	2.33	15:00
Sleepiness (F)	*t*(54) = 0.323	10	+	+0.044	0.33	3.33	16:00
Sleepiness (F)	*t*(54) = 0.128	10	+	+0.017	0.33	4.33	17:00
Fatigue (F)	*t*(54) = 1.252	10	+	+0.170	0.33	0.33	13:00
Fatigue (F)	*t*(54) = 1.548	10	–	–0.209	0.33	1.33	14:00
Fatigue (F)	*t*(54) = 3.958	10	–	–0.515	0.33	2.33	15:00
Fatigue (F)	*t*(54) = 5.474	10	–	–0.689	0.33	3.33	16:00
Fatigue (F)	*t*(54) = 5.209	10	–	–0.660	0.33	4.33	17:00
Hayashi, Watanabe et al. (1999)							
Logical (P)	*t*(36) = 1.440	7	+	+0.238	0.33	0.67	15:00
Logical (P)	*t*(36) = 0.507	7	+	+0.084	0.33	1.67	16:00
Logical (P)	*t*(36) = 0.621	7	+	+0.103	0.33	2.67	17:00
Calc (P)	*t*(36) = 1.131	7	+	+0.187	0.33	0.67	15:00
Calc (P)	*t*(36) = 2.008	7	+	+0.329	0.33	1.67	16:00
Calc (P)	*t*(36) = 1.864	7	+	+0.306	0.33	2.67	17:00
Visual Det (P)	*t*(36) = 1.070	7	+	+0.177	0.33	0.67	15:00
Visual Det (P)	*t*(36) = 0.876	7	+	+0.145	0.33	1.67	16:00
Visual Det (P)	*t*(36) = 0.564	7	+	+0.094	0.33	2.67	17:00
Aud Vigil (P)	*t*(36) = 1.266	7	+	+0.209	0.33	0.67	15:00
Aud Vigil (P)	*t*(36) = 1.331	7	+	+0.220	0.33	1.67	16:00
Aud Vigil (P)	*t*(36) = 0.839	7	+	+0.139	0.33	2.67	17:00
Sleepiness (F)	*t*(36) = 2.726	7	+	+0.440	0.33	0.67	15:00
Sleepiness (F)	*t*(36) = 2.025	7	+	+0.331	0.33	1.67	16:00
Sleepiness (F)	*t*(36) = 1.469	7	+	+0.242	0.33	2.67	17:00
Fatigue (F)	*t*(36) = 0.206	7	–	–0.034	0.33	0.67	15:00
Fatigue (F)	*t*(36) = 2.311	7	–	–0.376	0.33	1.67	16:00
Fatigue (F)	*t*(36) = 2.689	7	–	–0.434	0.33	2.67	17:00
Horne & Reyner (1996)							
KSS (F)	*t*(18) = 3.920	10	+	+0.827	0.25	0.50	15:45
Takahashi & Arito (2000)							
Logical (P)	*t*(55) = 1.094	12	+	+0.147	0.25	0.50	13:15
Logical (P)	*t*(55) = 1.824	12	+	+0.244	0.25	2.00	14:45
Logical (P)	*t*(55) = 0.608	12	+	+0.082	0.25	3.50	16:15
Logical (P)	*t*(55) = 2.797	12	+	+0.369	0.25	5.00	17:45
RT (P)	*t*(55) = 1.882	12	+	+0.251	0.25	0.50	13:15
RT (P)	*t*(55) = 2.425	12	+	+0.321	0.25	2.00	14:45
RT (P)	*t*(55) = 1.951	12	+	+0.260	0.25	3.50	16:15
RT (P)	*t*(55) = 2.563	12	+	+0.339	0.25	5.00	17:45
Digit Span (P)	*t*(55) = 1.319	12	+	+0.177	0.25	0.50	13:15
Digit Span (P)	*t*(55) = 2.002	12	+	+0.267	0.25	2.00	14:45
Digit Span (P)	*t*(55) = 1.739	12	+	+0.232	0.25	3.50	16:15
Digit Span (P)	*t*(55) = 0.949	12	+	+0.128	0.25	5.00	17:45
Sleepiness (F)	*t*(55) = 4.534	12	+	+0.579	0.25	0.50	13:15
Sleepiness (F)	*t*(55) = 5.069	12	+	+0.639	0.25	2.00	14:45
Sleepiness (F)	*t*(55) = 3.480	12	+	+0.454	0.25	3.50	16:15
Sleepiness (F)	*t*(55) = 5.258	12	+	+0.660	0.25	5.00	17:45
Takahashi et al. (1998)							
Sleepiness (F)	*t*(54) = 2.981	10	+	+0.395	0.25	0.75	13:30
Sleepiness (F)	*t*(54) = 2.799	10	+	+0.372	0.25	3.75	16:30
Sleepiness (F)	*t*(54) = 1.931	10	+	+0.260	0.75	0.75	13:15
Sleepiness (F)	*t*(54) = 3.792	10	+	+0.495	0.75	3.25	16:30

TABLE 1 (continued)

Study/Measure	Statistic (*df*)	*N*	DOE	Effect Size	Nap Duration	Postnap Interval	Time of Day
Tietzel & Lack (2001)							
Digit Subs (P)	*t*(22) = 3.989	12	+	+0.772	0.17	0.08	15:15
Digit Subs (P)	*t*(22) = 5.013	12	+	+0.929	0.17	0.58	15:45
Digit Subs (P)	*t*(22) = 3.337	12	–	–0.662	0.50	0.08	15:15
Digit Subs (P)	*t*(22) = 1.188	12	+	+0.251	0.50	0.58	15:45
Letter canc(P)	*t*(22) = 2.895	12	+	+0.584	0.17	0.08	15:15
Letter canc(P)	*t*(22) = 5.679	12	+	+1.023	0.17	0.58	15:45
Letter canc(P)	*t*(22) = 3.340	12	–	–0.663	0.50	0.08	15:15
Letter canc(P)	*t*(22) = 0.220	12	–	–0.047	0.50	0.58	15:45
Sleepiness (F)	*t*(22) = 2.585	12	+	+0.526	0.17	0.08	15:15
Sleepiness (F)	*t*(22) = 2.277	12	+	+0.468	0.17	0.58	15:45
Sleepiness (F)	*t*(22) = 2.277	12	+	+0.468	0.17	1.00	16:10
Sleepiness (F)	*t*(22) = 2.100	12	–	–0.434	0.50	0.08	15:15
Sleepiness (F)	*t*(22) = 0.000	12	+	+0.000	0.50	0.58	15:45
Sleepiness (F)	*t*(22) = 0.700	12	+	+0.149	0.50	1.00	16:10
Tilley & Wilkinson (1984)							
RT (P)	*t*(42) = 5.217	8	–	–0.737	4.00	9.50	13:30
RT (P)	*t*(42) = 3.083	8	–	–0.459	4.00	14.00	18:00
RT (P)	*t*(42) = 7.351	8	–	–0.973	4.00	19.00	23:00
RT (P)	*t*(42) = 10.194	8	–	–1.235	4.00	33.50	13:30
RT (P)	*t*(42) = 2.134	8	–	–0.324	4.00	5.50	13:30
RT (P)	*t*(42) = 1.422	8	–	–0.218	4.00	10.00	18:00
RT (P)	*t*(42) = 5.453	8	–	–0.765	4.00	15.00	23:00
RT (P)	*t*(42) = 9.485	8	–	–1.174	4.00	29.50	13:30
RT (P)	*t*(42) = 2.134	8	+	+0.324	8.00	5.50	13:30
RT (P)	*t*(42) = 7.114	8	+	+0.949	8.00	10.00	18:00
RT (P)	*t*(42) = 0.236	8	+	+0.036	8.00	15.00	23:00
RT (P)	*t*(42) = 2.134	8	+	+0.324	8.00	29.50	13:30

Note. Measure: P = performance; F = fatigue. DOE: Direction of effect (+ = better than baseline, – = worse than baseline). Effect size: Z_{Fisher}. Nap duration: in hours or fractions thereof. Postnap interval: in hours or fractions thereof. AddCorr = additions correct; DSS = digit symbol substitution; POMS = Profile of Mood States; CAS = Visual Analog Scale; KSS = Karolinska Sleepiness Scale; Calc = calculation; Visual Det = visual detection; Aud Vigil = auditory vigilance; RT = reaction time; Digit Subs = digit substitutions; Letter canc = letter cancellation.

standard array of cognitive laboratory tests, including tests of reaction time, visual vigilance, logical reasoning, and symbol digit substitution.

General effects. In order to examine the overall efficacy of naps as a fatigue countermeasure, we combined the significance levels and effect sizes for all hypothesis tests (weighting each hypothesis test by its corresponding sample size; see Mullen, 1989). The k = 178 hypothesis tests rendered a highly significant, Z = 10.877, p = 1.95E-23, extremely weak, $\overline{Z}_{Fisher}$ = –0.015, $\overline{r}$ = –.015, deterioration relative to baseline. We note that whereas the average effect is a significant yet weak deterioration relative to baseline, Table 1 indicates that in some cases, naps result in a return to baseline conditions (as indicated by effect sizes hovering around zero), and in some cases, naps result in a recovery from sleep loss exceeding baseline performance (as indicated by positive effect sizes). Further analysis of moderators of these effects will allow us to examine the conditions that lead to these negative and positive effects.

The relative effects of naps on performance and fatigue. In order to examine the relative effects of naps on performance as compared with their effects on fatigue, we combined the significance levels and effect sizes for hypothesis tests within each type of outcome measure (weighting each hypothesis test by its corresponding sample size; see Mullen, 1989). The k = 118 hypothesis tests for the effects of naps on performance rendered a significant, Z = 3.806, p = .00007, albeit negligible, $\overline{Z}_{Fisher}$ = 0.007, $\overline{r}$ = .007, improvement relative to baseline. The k = 60 hypothesis tests for the effects of naps on fatigue rendered a highly significant, $Z = 11.774$, $p = 6.28E\text{-}26$, weak, $\bar{Z}_{Fisher} = -0.048$, $\bar{r} = -0.048$, deterioration relative to baseline. A focused comparison of effect sizes is a technique that indicates the extent to which an effect size is significantly predictable in some systematic, specifiable manner (see Mullen, 1989) and can be applied to provide a test of the significance of the difference between the effects of naps on performance and the effects of naps on fatigue. There was no significant difference between the effects of naps on these two outcome measures, $Z = 0.115$, $p = .454$. Thus the effects of naps on measures of performance were not significantly different from the effects of naps on measures of fatigue.

It is also informative to examine differences in effect sizes for published versus unpublished studies. The results for the $k = 145$ published effect sizes, $\bar{r} = -.014$, and the results for the $k = 33$ unpublished effect sizes, $\bar{r} = -.023$, were not significantly different, $Z = 0.488$, $p = .3128$. Taking measurement type into account, the results for the $k = 97$ published performance effect sizes, $\bar{r} = .012$, and the results for the $k = 21$ unpublished performance effect sizes, $\bar{r} = -.025$, were not significantly different, $Z = 0.061$, $p = .4756$. Also, the results for the $k = 48$ published fatigue effect sizes, $\bar{r} = -.054$, and the results for the $k = 12$ unpublished fatigue effect sizes, $\bar{r} = -.019$, were not significantly different, $Z = 0.888$, $p = .1873$. Thus there were no differences between published and unpublished results in this meta-analytic database.

The effect of nap duration. In order to examine the effect of nap duration on the efficacy of naps as a fatigue countermeasure, the effect size for each hypothesis test was correlated with the duration (in hours or fractions thereof) of the nap for each hypothesis test. For the $k = 118$ hypothesis tests for the effects of naps on performance, longer duration naps led to marginally significantly less beneficial effects of naps, $r = -.109$, $Z = 1.336$, $p = .091$. This pattern of results is presented in Figure 1a. For the $k = 60$ hypothesis tests for the effects of naps on fatigue, longer duration naps led to significantly less beneficial effects of naps, $r = -.286$, $Z = 2.675$, $p = .004$. This pattern of results is presented in Figure 1b.

The effect of postnap interval. In order to examine the effect of postnap interval on the efficacy of naps as a fatigue countermeasure, the effect size for each hypotheses test was correlated with the postnap interval (in hours or fractions thereof) for each hypothesis test. For the $k = 118$ hypothesis tests for the effects of naps on performance, longer postnap intervals did lead to significantly less beneficial effects of naps, $r = -.361$, $Z = 5.211$, $p = 1.00E\text{-}7$. This pattern of results is presented in Figure 2a. For the $k = 60$ hypothesis tests for the effects of naps on fatigue, longer postnap intervals also led to significantly less beneficial effects of naps, $r = -.404$, $Z = 3.889$, $p = .00005$. This pattern of results is presented in Figure 2b.

The interactive effects of nap duration and postnap interval. It should be noted that a possible confound exists in the foregoing analyses of nap duration and postnap interval. Specifically, across all $k = 178$ hypothesis tests, a significant correlation was obtained between nap duration and postnap interval, $r(176) = .605$, $p = 1.47E\text{-}17$. In other words, studies that happened to employ longer naps also happened to measure the effects of naps over longer postnap intervals. This could simply reflect the realistic happenstance of studies differing in total duration. At any rate, this raises the serious possibility that the effects of nap duration we have reported thus far might be an epiphenomenon of more fundamental effects of postnap interval (or, vice versa).

In an effort to examine this possibility, we applied a more complex meta-analytic model testing procedure that has been effectively employed in the past (see Mullen & Copper, 1994) to these data. Specifically, nap duration was regressed upon postnap interval, and the residuals from this regression were then used as a new predictor. This new predictor represented the independent effects of nap duration (partialling out the effects of postnap interval). Similarly, postnap interval was regressed upon nap duration, and the residuals from this regression were then used as a new predictor. This new predictor represented the independent effects of postnap interval (partialling out the effects of nap duration). The significance of the independent prediction of effect sizes by each of these two new predictors was tested by focused comparisons of effect sizes (see Mullen, 1989; Mullen & Copper, 1994).

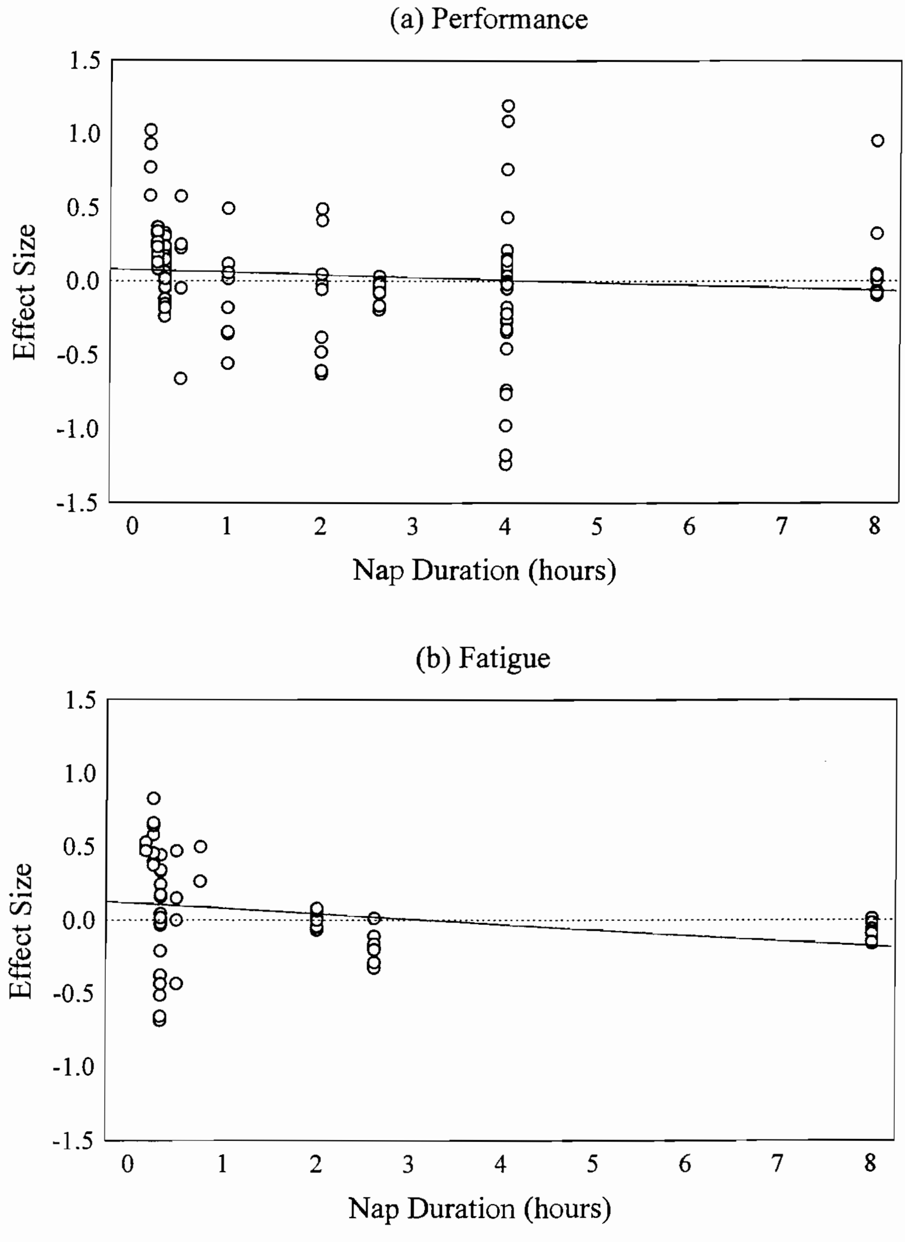

Figure 1. Effects of nap duration.

For the k = 118 hypothesis tests for the effects of naps on performance, nap duration was a significant predictor of the beneficial effects of naps after the effects of postnap intervals were partialled out, $r = .134$, $Z = 1.709$, $p = .044$. Also, postnap interval was still a significant predictor of the beneficial effects of naps even after the effects of nap durations were partialled out, $r = -.369$, $Z = 5.595$, $p = 1.26\text{E-}8$. Thus performance improved after longer naps, and the beneficial effects of naps deteriorated after longer postnap intervals.

A multiple regression analysis provides a means of specifying the precise effects of naps on performance as a function of both nap duration and postnap interval. Specifically, consider the multiple regression equation for the performance hypothesis tests: $Z_{\text{Fisher}} = 0.108 + 0.027$ (nap duration) – 0.017 (postnap interval). By substituting various nap durations and various postnap intervals, one can make very precise point predictions. In addition, the statistical significance of the foregoing analyses suggests that these point predictions are likely to be

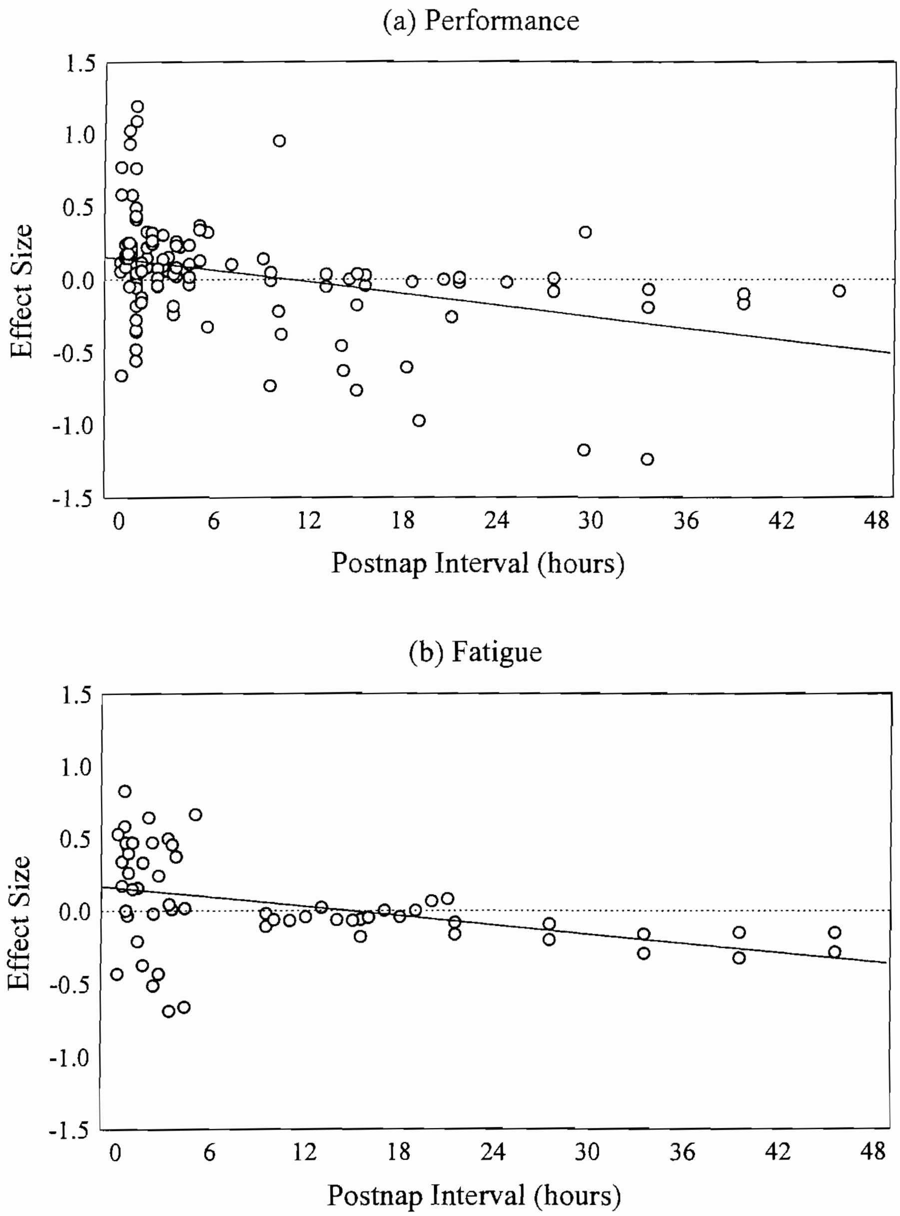

Figure 2. Effects of postnap interval.

extremely accurate. For example, consider the application of this approach depicted in Figure 3a. A 15-min nap actually reverses the effects of sleep deprivation (returning performance to its baseline level), at least for a few hours immediately upon waking from the nap. A 4-hr nap reverses the effects of sleep deprivation (returning performance to, or exceeding, its baseline level), for a postnap interval of up to 10 hr.

This approach was repeated for the $k = 60$ hypothesis tests for the effects of naps on fatigue. Nap duration was no longer a significant predictor of the beneficial effects of naps after the effects of postnap intervals were partialled out, $r = -.032$, $Z = 0.372$, $p = .355$. Also, postnap interval was still a significant predictor of the beneficial effects of naps even after the effects of nap durations were partialled out, $r = -.287$, $Z = 3.463$, $p = .0003$. Thus fatigue was not affected by nap duration, but the beneficial effects of naps deteriorated after longer postnap intervals.

Even though nap duration was not a significant independent predictor of the effects of naps

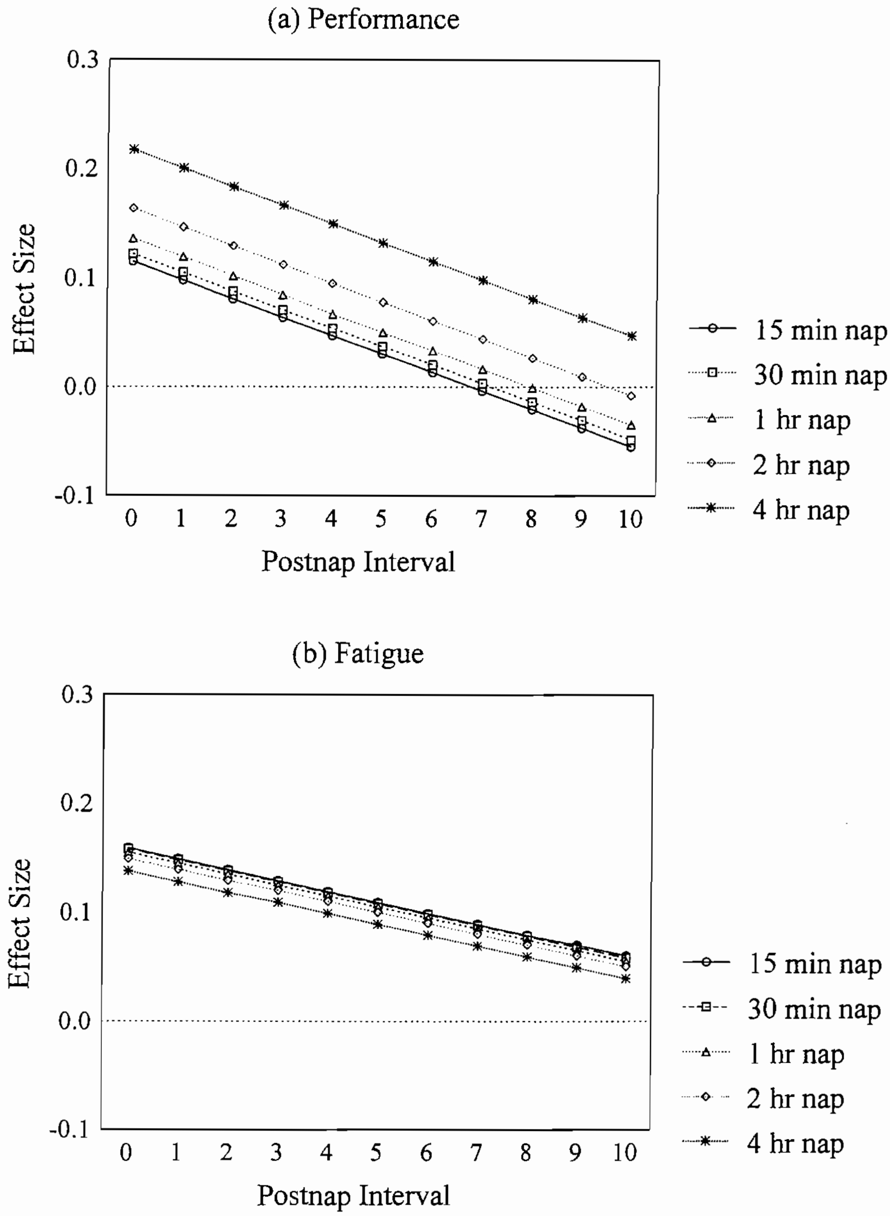

Figure 3. Effects of nap duration and postnap interval.

on fatigue in these analyses, we present these results for comparability with those for performance. The multiple regression equation for the fatigue hypothesis tests is $Z_{\text{Fisher}} = 0.160 - 0.005$ (nap duration) – 0.010 (postnap interval). Again, by substituting various nap durations and various postnap intervals, one can make precise point predictions. For example, consider the application of this approach depicted in Figure 3b. Naps (of basically any duration) actually reverse the effects of sleep deprivation (returning fatigue to its baseline level), for postnap intervals of up to 10 hr.

The effect of circadian rhythm. Several authors have suggested that variation across studies in the effectiveness of naps might be a function of natural variation in performance and fatigue as a function of time of day, reflecting the effects of circadian rhythm (e.g., Bonnet, 1990; Gillberg, 1985). In order to examine the effects of circadian rhythm, a numerical index of circadian rhythm had to be derived from the previously published literature on circadian rhythms in humans. Specifically, Broughton (1994, Figure 1, p. 25) summarized and synthesized the results of several studies examining the periodicity of "sleepiness" over a 24-hr period. The curve-fitted function developed by Broughton (1994) is presented in Figure 4. Note that this curve-fitted function depicts a nonlinear circadian rhythm in sleepiness over a 24-hr period.

In Figure 5, the effects of naps are plotted as a function of time of day, with the circadian rhythm derived from Broughton (1994) superimposed onto the graph. Thus, whereas the figure is depicted as a (linear) portrayal of the effects of naps at various times of day, effect sizes should be arrayed along the (nonlinear) circadian rhythm function if the effects of naps are influenced by circadian rhythm. The focused comparisons we report later test the extent to which the effects of naps are arrayed along the (nonlinear) circadian rhythm function superimposed onto each graph.

The effect size for each hypothesis test was correlated with the index of circadian "sleepiness" based on the time at which the measurements were obtained. For the $k = 118$ hypothesis tests for the effects of naps on performance, there was no significant prediction of the beneficial effects of naps as a function of circadian rhythm, $r = -.080$, $Z = 1.196$, $p = .116$. This pattern of results is presented in Figure 5a. For the $k = 60$ hypothesis tests for the effects of naps on fatigue, there was no significant prediction of the beneficial effects of naps as a function of circadian rhythm, $r = -.080$, $Z = 0.962$, $p = .168$. This pattern of results is presented in Figure 5b. Thus there is no evidence supporting the notion that the effects of naps are moderated by the point during the circadian rhythm at which those effects are measured.

It should be noted that there was no indication of any possible confound in the effects of nap duration and postnap interval by circadian rhythms. Specifically, across all $k = 178$ hypothesis tests, there was no significant correlation obtained between the index of circadian rhythm and nap duration, $r(176) = .110$, $p = .144$, or between the index of circadian rhythm and postnap interval, $r(176) = .011$, $p = .884$.

The possibility of sleep inertia. In an effort to examine the possibility of sleep inertia, we studied the relation between effect sizes and postnap intervals for the period of the first hour after waking from the nap. Presented in Figure 6, this amounts to an expanded presentation of the leftmost region of Figure 2. For the $k = 41$ hypothesis tests for the effects of naps on performance with a postnap interval of 1 hr or less, there was no variation in the beneficial effects of naps as a function of the postnap interval immediately after waking, $r = .023$, $Z = 0.186$, $p = .426$. This pattern of results is presented in Figure 6a. For the $k = 14$ hypothesis tests for the effects of

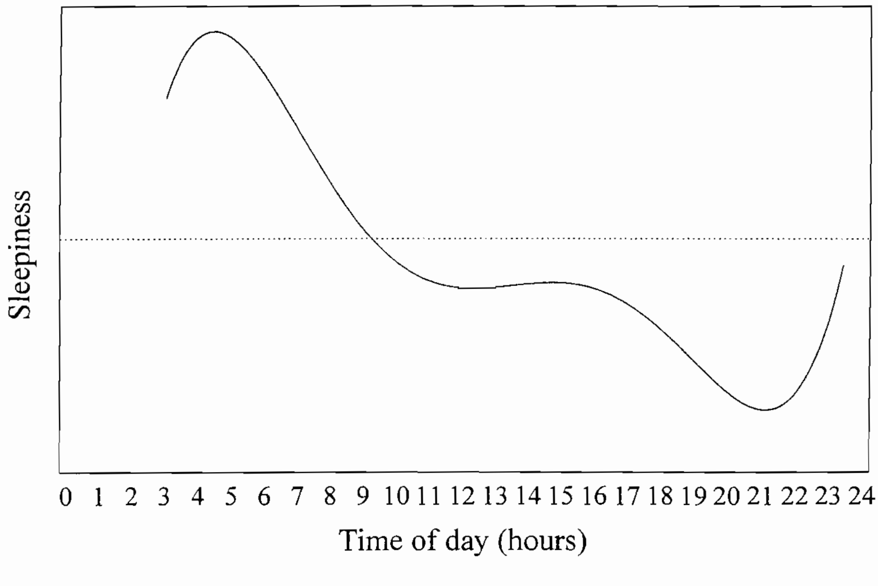

Figure 4. Circadian rhythm in "sleepiness." From "Important Underemphasized Aspects of Sleep Onset," by R. Broughton, in *Sleep Onset: Normal and Abnormal Processes* (p. 25), edited by R. D. Oglive & J. R. Harsh, 1994, Washington, DC: American Psychological Association. Copyright © 1994 by the American Psychological Association. Adapted with permission.

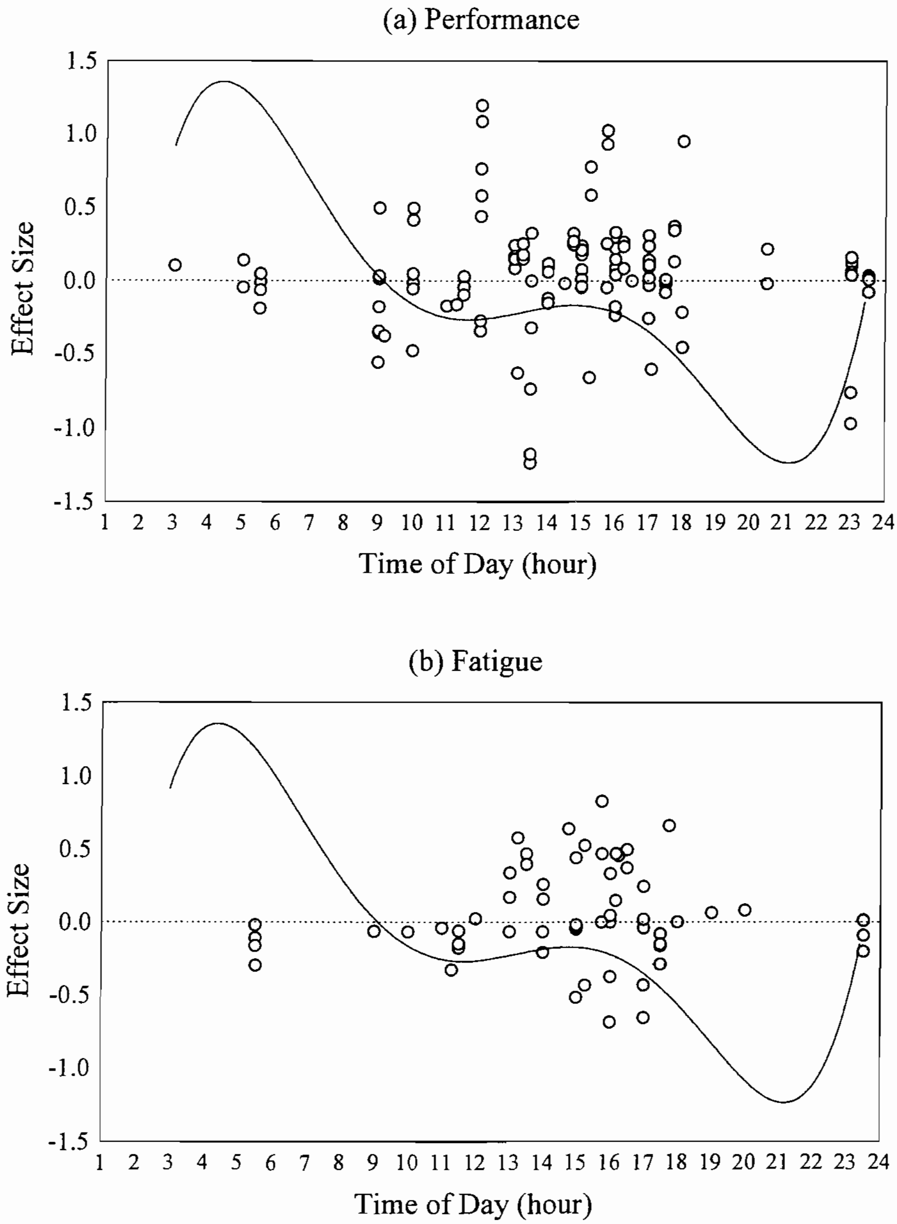

Figure 5. Effects of circadian rhythm.

naps on fatigue with a postnap interval of 1 hr or less, there was no variation in the beneficial effects of naps as a function of the postnap interval immediately after waking, $r = .181$, $Z = 0.591$, $p = .277$. This pattern of results is presented in Figure 6b. It can be seen that there is no evidence supporting the notion of sleep inertia on performance or fatigue.

DISCUSSION

We have attempted to integrate the results of every study on the effectiveness of naps as a fatigue countermeasure that was accessible via a comprehensive search procedure and that contained data that allowed precise statistical tests of the effects of naps on performance or fatigue to be derived. We believe the results extend current understanding of nap effects and provide more precise guidelines for managing naps as a fatigue countermeasure than were previously available. In the following, we summarize these results and discuss the strengths and weaknesses of this study.

Overall, the results of this integration indicated that the average effect of naps for individuals

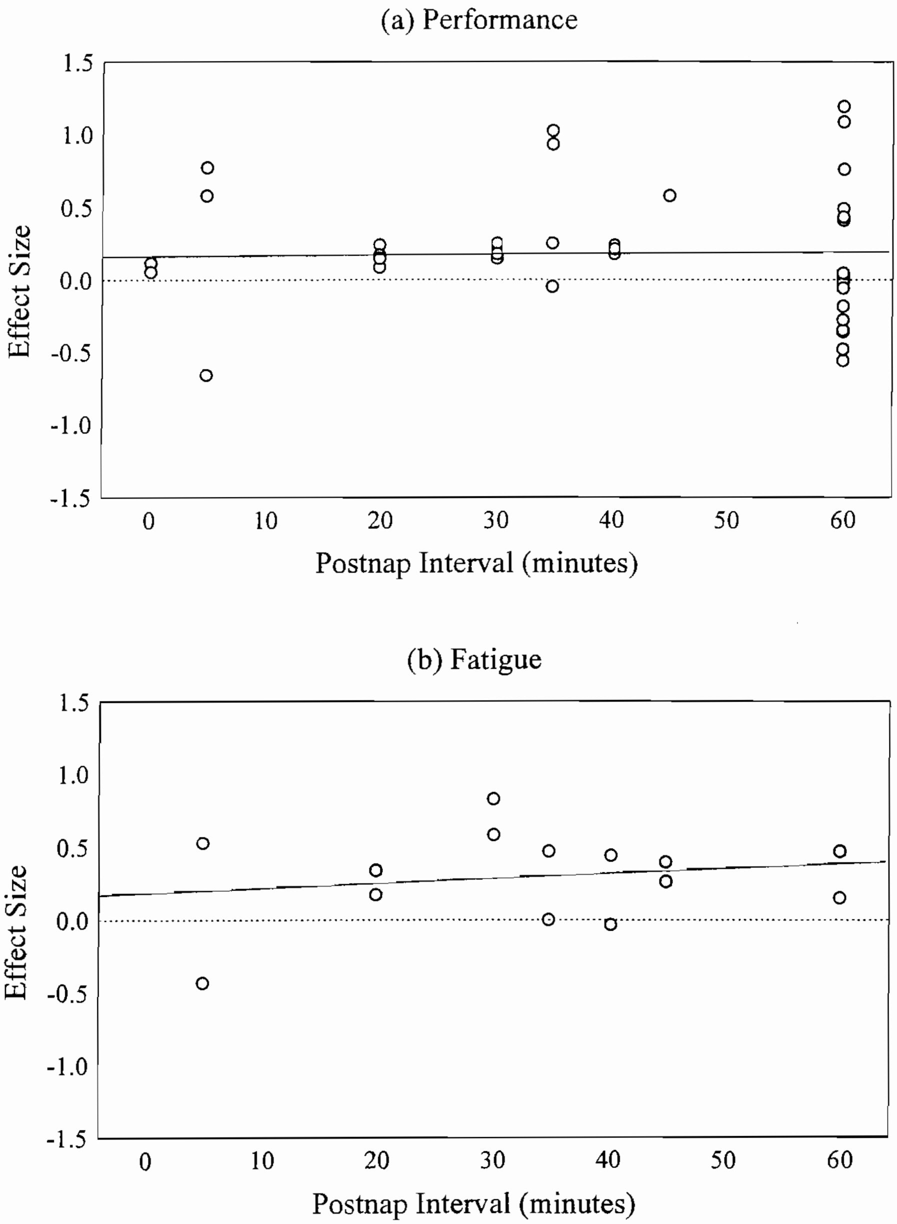

Figure 6. Possibility of sleep inertia.

who had been up for an extended period of time was a significant, albeit weak, decrement relative to baseline. Note that within this database, individuals' postnap performance was compared with their own baseline prior to the extended operation. That is, they were tested at a baseline, kept awake for a period of time, allowed a nap, and then tested again. It is not too surprising that overall, their performance after they were fatigued and allowed a nap was somewhat poorer than their performance prior to being fatigued. Moreover, this result collapses across whether naps were of short or long duration and whether the assessment of nap effects was conducted at a brief or long postnap interval. The overall results indicate that naps may be able to *reduce* the effects of sleep loss (as indicated by effects that hovered around zero). However, contrary to the claims of some narrative reviews (e.g., Bonnet, 1990; Dinges & Broughton, 1989; Gillberg, 1985; Rosekind et al., 1995), under certain conditions naps can even *reverse* the effects of sleep deprivation.

We further found that the overall effect of naps was essentially equivalent for measures of performance and for measures of fatigue. This runs counter to Gillberg's (1985, p. 86) speculation that naps would exert a noticeable effect on fatigue even though performance might remain relatively unaffected. However, performance and fatigue were differentially affected by nap duration and postnap interval, as noted in the following.

We found that performance improved after longer naps and that the beneficial effects of naps deteriorated after longer postnap intervals. In contrast, fatigue was not affected by nap duration (thus people may report feeling less fatigued after a nap of almost any duration), and again the beneficial effects of naps deteriorated after longer postnap intervals. We are further able to specify in precise terms the predictable effects of naps of a given duration over postnap intervals of varying length. On the one hand, if one knows how long the postnap interval is going to be, one can specify the precise nap duration required to bring performance back to baseline levels. On the other hand, if one knows how long the nap duration can be, one can specify the precise postnap interval during which performance can be maintained at baseline levels.

In a recent review of sleep loss and fatigue in medical personnel, Veasey et al. (2002) offered recommendations for implementing naps. On one hand, they concluded, "A 2 to 8 hour nap prior to 24 hours of sleep loss can improve vigilance," and "Two-hour naps every twelve hours ameliorate performance decrements across 88 hours of sleep deprivation" (p. 1122–1123). On the other hand, they also concluded that "naps as short as 15 minutes can significantly ameliorate the performance decrements if provided at 2 to 3 hour intervals" (p. 1122).

As a practical guideline, these recommendations are quite broad, calling for a 2- to 8-hr nap, a 15-min nap, or a 2-hr nap every 12 hr. Moreover, these recommendations seem to miss the mark established by the weight of empirical evidence. Consider the recommendation for a 2-hr nap every 12 hr. Using the regression equation for the effects of naps on performance as a function of nap duration and postnap interval, we found that 2-hr naps every 12 hr render a decrement in performance relative to baseline, Z_{Fisher} = 0.108 + 0.027(2-hr duration) – 0.017(12-hr postnap interval) = –0.042. However, a 2-hr nap *can* ameliorate performance decrements attributable to fatigue for up to 9.5 hr, Z_{Fisher} = 0.108 + 0.027(2-hr duration) – 0.017(9.5-hr postnap interval) = 0.0005. Similarly, consider the recommendation for a 15-min nap every 2 to 3 hr. Using the regression equation, we found that 15-min naps every 2.5 hr render a genuine improvement in performance relative to baseline, Z_{Fisher} = 0.108 + 0.027(0.25-hr duration) – 0.017(2.5-hr postnap interval) = +0.072. However, a 15-min nap can *also* ameliorate performance decrements attributable to fatigue for up to 6.75 hr, Z_{Fisher} = 0.108 + 0.027(0.25-hr duration) – 0.017(6.75-hr postnap interval) = 0.000.

In other words, previous recommendations, based on a narrative reading of the research on the effects of naps, have been just as likely to overestimate the beneficial effects of naps ("two-hour naps every twelve hours ameliorate performance decrements"; Veasey et al., 2002, pp. 1122–1123) as to underestimate the effects of naps ("naps as short as 15 minutes can significantly ameliorate the performance decrements if provided at 2 to 3 hour intervals"; Veasey et al., 2002, p. 1122). The current approach allows us to provide recommendations for implementing naps that are considerably more precise than a 15-min to 8-hr range.

We found that for both performance and fatigue, there is no evidence supporting the notion that the effects of naps are moderated by the point during the circadian rhythm at which those effects are measured. This runs counter to suggestions that variation across studies in the effectiveness of naps on performance might be a function of natural variation in performance efficiency as a function of the time of day, reflecting the effects of circadian rhythm. This failure of circadian rhythms to account for variation in the effects of naps, and the overall lack of any association between circadian rhythm and nap duration or postnap interval, suggest that the patterns we have described for the effects of nap duration and postnap interval are quite robust.

In examining the possibility of sleep inertia, we found no variation in fatigue or performance within the 1-hr period immediately following a nap. Moreover, Rosekind et al. (1995) noted that even if one considers the possibility that sleep inertia may occur when naps are used in an operational setting, one must balance this concern against the overall improvements in performance gained from the nap itself. Our results suggest that at least within the range of naps observed within this database, sleep inertia does not seem to be a significant concern.

It is prudent to consider several limitations of the current research. First, the selection criteria for inclusion in this meta-analysis restricted studies to those that examined the effects of naps among a normal, nonclinical adult population. Caution should be taken in interpreting the results to other populations, including the elderly (Creighton, 1995) and those with sleep disorders (Helmus et al., 1997). Second, the results of this study are restricted to the effects of naps on performance and subjective fatigue. We do not know the extent to which these effects generalize to physiological indicators such as electroencephalographic or electro-oculographic activity. Third, other potentially informative moderators exist that we were not able to examine within this database, such as the effect of type of task. The number of hours of wakefulness prior to baseline assessment is another such variable; however, the existing studies in the database did not allow this measure to be extracted.

Finally, these results are only one small part of the puzzle in addressing problems of sleep loss and fatigue. Fatigue is a complex and multifaceted subject that requires complex and multifaceted solutions. This may include research on effective fatigue countermeasures as well as attention to operator education and training, scheduling practices, technology, and policy. Thus, naps are not the solution to the problem of fatigue, yet they do provide an effective fatigue countermeasure that should be incorporated into an integrated fatigue management program. By establishing the existence of nap effects, this research contributes to further development of theory and practical applications in this area.

ACKNOWLEDGMENTS

Funding for this research was provided by the National Aeronautics and Space Administration.

REFERENCES

Akerstedt, T., & Torsvall, L. (1985). Napping in shift work. *Sleep, 8,* 105-109.

Badia, P., & Harsh, J. (1985). *Auditory evoked potentials as a function of sleep deprivation and recovery sleep* (Report DAMD17-84-C-4084). Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Baker, K., Olson, J., & Morisseau, D. (1994). Work practices, fatigue, and nuclear power plant safety performance. *Human Factors, 36,* 244–257.

Bertelson, A. D. (1979). *Effects of napping and bedrest on performance and mood.* Unpublished doctoral dissertation, Ohio State University.

Bonnet, M. H. (1986). Performance and sleepiness as a function of frequency and placement of sleep disruption. *Psychophysiology, 23,* 263–271.

Bonnet, M. H. (1990). Dealing with shift work: Physical fitness, temperature, and napping. *Work and Stress, 4,* 261–274.

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

Bonnet, M. H., & Arand, D. L. (1995). Consolidated and distributed nap schedules and performance. *Journal of Sleep Research, 4,* 71–77.

Bonnet, M. H., Gomez, S., Wirth, O., & Arand, D. L. (1995). The use of caffeine versus prophylactic naps in sustained performance. *Sleep, 18,* 97–104.

Broughton, R. (1994). Important underemphasized aspects of sleep onset. In R. D. Oglive & J. R. Harsh (Eds.), *Sleep onset: Normal and abnormal processes* (pp. 19–35). Washington, DC: American Psychological Association.

Caldwell, J. A. (1997). Fatigue in the aviation environment: An overview of the causes and effects as well as recommended countermeasures. *Aviation, Space, and Environmental Medicine, 68,* 932–938.

Caldwell, J. A., Jones, R. W., Caldwell, J. L., Colon, J., Pegues, A., Iverson, L., et al. (1997). *The efficacy of hypnotic-induced prophylactic naps for the maintenance of alertness and performance in sustained operations* (Tech. Report 97-10). Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory,.

Caldwell, J. L., Caldwell, J. A., Colon, J., Ruyak, P. S., Ramspott, S., Sprenger, W. D., et al. (1998). *Recovery of sleep, performance, and mood following 38 hours of sleep deprivation using naps as a countermeasure* (Tech. Report 98-37). Ft. Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Chan, O. Y., Phoon, W. H., Gan, S. L., & Ngui, S. J. (1989). Sleep-wake patterns and subjective sleep quality of day and night workers: Interaction between napping and main sleep episodes. *Sleep, 12,* 439–448.

Creighton, C. (1995). Effects of afternoon rest on the performance of geriatric patients in a rehabilitation hospital: A pilot study. *American Journal of Occupational Therapy, 49,* 775–779.

Daiss, S. R., Bertelson, A. D., & Benjamin, L. T. (1986). Napping vs. resting: Effects on performance and mood. *Psychophysiology, 23,* 82–88.

DeValk, E., DeGroot, E., & Cluydts, R. (2003). Effects of slow-release caffeine and a nap on driving simulator performance after partial sleep deprivation. *Perceptual and Motor Skills, 96,* 67–78.

Dinges, D. F., & Broughton, R. J. (1989). The significance of napping: A synthesis. In D. F. Dinges & R. J. Broughton (Eds.), *Sleep and alertness: Chronobiological, behavioral, and medical aspects of napping* (pp. 299–308). New York: Raven Press.

Dinges, D. F., Orne, E. C., Evans, F. J., & Orne, M. T. (1981). Performance after naps in sleep-conducive and alerting environments. In L. C. Johnson, D. I. Tepas, W. P. Colquhon, & M. J. Colligan (Eds.), *Biological rhythms, sleep and shiftwork* (pp. 539–552). New York: S. P. Medical and Scientific Books.

Dinges, D. F., Orne, M. T., Whitehouse, W. G., & Orne, E. C. (1987). Temporal placement of a nap for alertness: Contributions of circadian phase and prior wakefulness. *Sleep, 10,* 313–329.

Duchon, J. C., Keran, C. M., & Smith, T. J. (1994). Extended workdays in an underground mine: A work performance analysis. *Human Factors, 36,* 258–268.

Gillberg, M. (1984). The effects of two alternative timings of a one-hour nap on early morning performance. *Biological Psychology, 19,* 45–54.

Gillberg, M. (1985). Effects of naps on performance. In S. Folkard & T. H. Monk (Eds.), *Hours of work* (pp. 77–86). New York: Wiley.

Gillberg, M., Kecklund, G., Axelsson, J., & Akerstedt, T. (1996). The effect of a short daytime nap after restricted night sleep. *Sleep, 19,* 570–575.

Hartley, L. R. (1974). A comparison of continuous and distributed reduced sleep schedules. *Quarterly Journal of Experimental Psychology, 26,* 8–14.

Hayashi, M., Ito, S., & Hori, T. (1999). The effects of a 20-minute nap at noon on sleepiness, performance, and EEG activity. *International Journal of Psychophysiology, 32,* 173–180.

Hayashi, M., Watanabe, M., & Hori, T. (1999). The effects of a 20-minute nap in the mid-afternoon on mood, performance, and EEG activity. *Clinical Neurophysiology, 110,* 272–279.

Helmus, T., Rosenthal, L., Bishop, C., Roehrs, T., Syron, M. L., & Roth, T. (1997). The alerting effects of short and long naps in narcoleptic sleep deprived, and alert individuals. *Sleep, 20,* 251–257.

Horne, J. A., & Reyner, L. A. (1996). Counteracting driver sleepiness: Effects of napping, caffeine, and placebo. *Psychophysiology, 33,* 306–309.

Johnson, L. C., Freeman, C. R., Spinweber, C. L., & Gomez, S. A. (1988). *The relationship between subjective and objective measures of sleepiness* (Tech. Report 88-50). San Diego, CA: Naval Health Research Center.

Lavie, P., & Weler, B. (1989). Timing of naps: Effects on post-nap sleepiness levels. *Electroencephalography and Clinical Neurophysiology, 72,* 218–224.

Lindbergh, C. A. (1953). *The Spirit of St. Louis.* New York: Scribner's.

Moses, J., Lubin, A., Naitoh, P., & Johnson, L. C. (1978). Circadian variation in performance, subjective sleepiness, sleep, and oral temperature during an altered sleep-wake schedule. *Biological Psychology, 6,* 301–308.

Mullen, B. (1989). *Advanced BASIC meta-analysis.* Hillsdale, NJ: Erlbaum.

Mullen, B., & Copper, C. (1994). The relation between group cohesiveness and performance: An integration. *Psychological Bulletin, 115,* 210–227.

Mullen, B., Driskell, J. E., & Salas, E. (1998). Meta-analysis and the study of group dynamics. *Group Dynamics, 2,* 213–229.

Naitoh, P., & Angus, R. G. (1987). *Napping and human functioning during prolonged work* (NHRC-87-21). San Diego, CA: Naval Health Research Center.

Naitoh, P., Englund, C. E., & Ryman, D. H. (1983). *Extending human effectiveness during sustained operations through sleep management* (NHRC-83-13). San Diego, CA: Naval Health Research Center.

National Research Council. (2001). *Caffeine for the sustainment of mental task performance: Formulations for military operations.* Washington, DC: National Academy Press.

National Transportation Safety Board. (1989). *Grounding of U.S. tankship Exxon Valdez on Bligh Reef, Prince William Sound near Valdez, AK* (NTSB/ MAR-90-04). Washington, DC: Author.

National Transportation Safety Board. (1994). *Uncontrolled collision with terrain American International Airways Flight 808, Douglas DC-8-61, N814CK U.S. Naval Air Station Guantanamo Bay, Cuba August 18, 1993* (NTSB/AAR-94-04). Washington, DC: Author.

National Transportation Safety Board. (1996). *Railroad accident report collision involving two New York City subway trains on the Williamsburg Bridge in Brooklyn, New York June 5, 1995* (NTSB/RAR-96-03). Washington, DC: Author.

Neri, D. F., Oyung, R. L., Colletti, L. M., Mallis, M. M., Tam, P. Y., & Dinges, D. F. (2002). Controlled breaks as a fatigue countermeasure on the flight deck. *Aviation, Space, and Environmental Medicine, 73,* 654–664.

Neville, K. J., Bisson, R. U., French, J., Boll, P. A., & Storm, W. F. (1994). Subjective fatigue of C-141 aircrews during Operation Desert Storm. *Human Factors, 36,* 339–349.

Ohayaon, M. M., & Zulley, J. (1999). Prevalence of naps in the general population. *Sleep and Hypnosis, 1,* 88–97.

Opstad, P. K., Ekanger, R., Nummestad, M., & Raabe, N. (1978). Performance, mood, and clinical symptoms in men exposed to prolonged, severe physical work and sleep deprivation. *Aviation, Space, and Environmental Medicine, 49,* 1065–1073.

Rosekind, M. R., Gander, P. H., Miller, D. L., Gregory, K. B., Smith, R. M., Weldon, K. J., et al. (1994). Fatigue in operational settings: Examples from the aviation environment. *Human Factors, 36,* 327–338.

Rosekind, M. R., Graeber, R. C., Dinges, D. F., Connell, L. J., Rountree, M. S., Spinweber, C. L., et al. (1994). *Crew factors in flight operations: IX. Effects of planned cockpit rest on crew performance and alertness in long-haul operations* (NASA Tech. Memorandum 108839). Washington, DC: National Aeronautics and Space Administration.

Rosekind, M. R., Smith, R. M., Miller, D. L., Co, E. L., Gregory, K. B., Webbon, L. L., et al. (1995). Alertness management: Strategic naps in operational settings. *Journal of Sleep Research, 4,* 62–66.

Schweitzer, P. K., Muehlbach, M. J., & Walsh, J. K. (1992). Countermeasures for night work performance deficits: The effect of napping or caffeine on continuous performance at night. *Work and Stress, 6,* 355–365.

Takahashi, M., & Arito, H. (2000). Maintenance of alertness and performance by a brief nap after lunch under prior sleep deficit. *Sleep, 23,* 813–819.

Takahashi, M., Fukuda, H., & Arito, H. (1998). Brief naps during post-lunch rest: Effects on alertness, performance, and autonomic balance. *European Journal of Applied Physiology, 78,* 93–98.

Taub, J. M. (1977). Napping behavior, activation, and sleep function. *Waking and Sleeping, 1,* 281–290.

Taub, J. M. (1979). Effects of habitual variations in napping on psychomotor performance, memory, and subjective states. *International Journal of Neuroscience, 9,* 97–112.

Taub, J. M. (1982). Effects of scheduled afternoon naps and bedrest on daytime alertness. *International Journal of Neuroscience, 16,* 107–127.

Thessing, V. C., Anch, A. M., Muehlbach, M. J., Schweitzer, P. K., & Walsh, J. K. (1994). Two- and four-hour bright light exposures differentially affect sleepiness and performance the subsequent night. *Sleep, 17,* 140–145.

Tietzel, A. J., & Lack, L. C. (2001). The short-term benefits of brief and long naps following nocturnal sleep restriction. *Sleep, 24,* 293–300.

Tilley, A. J., & Wilkinson, R. T. (1984). The effects of a restricted sleep regime on the composition of sleep and on performance. *Psychophysiology, 21,* 406–412.

Veasey, S., Rosen, R., Barzansky, B., Rosen, I., & Owens, J. (2002). Sleep loss and fatigue in residency training: A reappraisal. *Journal of the American Medical Association, 288,* 1116–1124.

Webb, W. B. (1987). The proximal effects of two and four hour naps within extended performance without sleep. *Psychophysiology, 24,* 426–429.

James E. Driskell is president and senior scientist at Florida Maxima Corporation, Winter Park, Florida. He received his Ph.D. from the University of South Carolina in 1981.

Brian Mullen is a professor of psychology at Syracuse University. He obtained his Ph.D. in psychology from the State University of New York at Albany in 1982.

Date received: February 11, 2003
Date accepted: December 22, 2004