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SLEEP LOSS AND COMPLEX TEAM PERFORMANCE

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Abstract

There are few objective assessments of the impact of sleep loss on team performance. The present study was designed to quantify the effects of fatigue on teams performing a complex task and to compare team data with individual data on a similar task. Participants were trained on a complex air battle management task (both in individual and team mode) for one week and then experienced a 36-hr period of sustained wakefulness. Forty-minute scenarios (individual and team) were iteratively completed throughout each experimental period alongside traditional cognitive performance tasks (e.g., simple math processing). Individual data showed the well-established performance reduction resulting from sleep loss and circadian variation at both the simple and complex task levels. Significant decrements were seen for both process measures (e.g., information gathering) and outcome measures (e.g., number of targets attacked) after sleep-loss on the complex task. In contrast, team scores on similar measures after sleep loss, did not degrade, and in some cases showed improvements relative to baseline (indicating a continuing team building process). Individual performance (both simple and complex) was significantly degraded during the early morning hours. Team data did not show the expected performance decrements.

Introduction

Fatigue, due to both sleep loss and circadian variation, and the resultant subjective and performance effects, have been extensively documented at the individual level. For a review, including the impact of fatigue upon decision-making see Harrison & Horne, 2000. However, very few studies have reported objective data regarding the effects of fatigue upon aspects of team performance. The research presented in this paper was designed to address the issue of fatigue on teams by examining complex team performance (using command and control simulations based upon demanding USAF operational tasks) in a sustained operations laboratory environment using USAF military personnel as research participants.

Teams may be defined as, "two or more individuals working toward a common goal in an interdependent fashion" (Salas, Dickinson, Converse, & Tannenbaum, 1992). Teams of individuals perform tasks ranging from the esoteric (e.g., battle management) to the every-day (e.g., administrative functions in offices). Many of these tasks are performed at all times of day or night (e.g., power plant operations) and after extended work periods (e.g., emergency medical surgery). It seems important therefore to be able to describe, quantifiably, how teams respond to fatiguing situations. Unfortunately, there is a definite lack of research literature on teams in sustained operating environments (Weaver, Bowers, & Salas, 2001). Crew resource management addresses fatigue as one of the factors of which crews should be made aware and trained to expect and control (Helmreich, Merritt, & Wilhelm, 1999); however, the specific effects of fatigue due to sleep loss upon team performance do not seem to be provided by this literature. (Hollenbeck, Ilgen, Tuttle, & Sego, 1995) performed research on sustained attention in a team environment using well-rested volunteers. These researchers found that decrements on vigilance tasks at the team level were similar to those at the individual level. After additional review they postulated that distractions amongst team members were the cause of some performance loss. In summary, while research programs have examined teams under stress (e.g., see the text by (Cannon-Bowers & Salas, 2000), there is currently little known about teams and fatigue.

Generally, complex performance may be divided into two distinct but related categories: process and outcome. Process measures record information on behaviors which must be taken in order to accomplish some goal. For example, a process measure might be the number of times an operator accesses a database to make a decision on the identity of an aircraft. Outcomes are the most commonly thought of types of measures and provide information on the results of a task (e.g., number of targets engaged). By assessing performance from these two perspectives we may understand not only what happened (e.g., did we win?), but also how it happened (e.g., what types of friendly assets were used to engage targets?). Additional metrics, like number of resources shared, become available as teams become the unit of analysis.

The greatest difference between the team and individual task environments is the interaction between any given individual and other humans (by definition of the tasks). This one difference has broad implications. In the team environment there is a potentially significant communication load and dependence upon others to accomplish one's own task. This likely has the effect of pulling attention from being solely focused 'on the screen' to a broader setting. Potentially, this has implications not only for what the operators respond to, but also for how they think (i.e., allows them to solve problems using different methods). Dependence on others creates a need to have awareness of your team mates' resources and status, establish group consensus, plan, and communicate. All of these processes make the team task different from a solo task.

Team performance is broadly composed of two components (Glickman, Zimmer, Montero, Guerette, & Salas, 1987): 1-taskwork (concerning task requirements), and 2-teamwork (concerning co-ordination amongst members). Thus to be an effective team member requires considerable knowledge and skill beyond the individual task level (see Stout, Salas, & Carson, 1994). It may be that a team can function well when its team members are tired, but if so, this continued performance is likely the result of some type of adaptation by the team members (e.g., to some extent the tired team is now composed of a different set of individuals than when it was rested).

The goal of this study was to objectively assess the effects of sleep loss on team performance within a command and control environment (i.e., an applied environment). The teams: were newly formed, were novices to the task, performed an analogue of a real-world task for which they had a professional alignment, were co-located, were non-hierarchical, and had distributed expertise (as a result of assigned roles). They performed a synthetic task that captured the essential function of air battle managers as identified though cognitive task analysis and subject matter expert input. To fully appreciate the potential effect of fatigue upon teams we sought to relate team performance to the vast literature on individual performance. One way to do this is to have a well-understood reference for comparison to the team data. To this end we compared changes on the team task with performance decrements observed on traditional individual tasks (e.g., simple mathematical processing). We selected two well-established individual tasks and collected data on them alongside our team task.

This study extends the work begun in a previous sleep deprivation study performed in our laboratory. In the previous study we observed that both team performance and individual performance declined (Whitmore, 2005). However, the fatigue effect upon teams seemed to be weaker than the effect upon individual performance. We could not solely attribute this difference to the presence of teams as the tasks performed were quite different. While performance on complex tasks has been shown to decrease after sleep deprivation (Harrison & Horne, 2000), it may be that the characteristics of the team task were more motivating than the simple tasks and that this increased motivation allowed for relatively improved performance. To somewhat address this issue, the current study included both an individual and team version of the complex command and control simulation.

Methods

Participants

A total of 30 junior USAF active-duty officers who were on hiatus from receiving

Air Battle Management Training at Tyndall AFB, Florida served as the participants. All participants were volunteers and signed an informed consent document which had been approved by the USAF Surgeon General, protocol #F-BR-2004-0041-H. The participants included 22 males and 8 females. Participants were formed into 10, 3-person teams. One team had three females, another team had two females, and three teams had one female. Prior to their arrival at Brooks City-Base, all participants had completed the Aerospace Basics Course. This course gave them background knowledge of doctrine, but no actual field or simulation experience in Air Battle Management. Exclusion criteria consisted of a history of sleep problems, and current use of medications for sleep, depression, or ADHD. The mean age of the participants was 26.1 (±2.6) years. Prior to the experimental session start on Friday morning, participants averaged 6.0 hrs of sleep (range 4.4 – 8.4 hrs). On Tuesday and Wednesday nights they reported 8.3 and 8.1 hrs of sleep respectively. In the 24hrs following the experimental session, participants averaged 16.6 hrs of recovery sleep (range 12.0 – 22.1).

Procedure

A total of 70 hours was required of each participant. Each participant went through 32 hours of training the 4 days prior to the experimental session (i.e., Monday through Thursday). Training on the tasks was spaced over the four days and consisted of 10 trials of the simple individual performance tasks, functional training on the synthetic task, 8 trials of the complex individual performance task, and 5 trials as a team on the team task. They then spent 36 hours in the laboratory without sleep (Friday morning to Saturday afternoon). Participants were driven to on-base housing following the experimental session and given 24 hours to rest. They then returned at 1400 hours the following day (Sunday) for a 2-hour recovery session. Scenario administration times in the experimental session were picked using predicted peaks and troughs of performance based upon historical performance patterns (see respective data tables for administration times).

Baseline performance on all measures was captured in the afternoon on the final day of training (Thursday). The experimental session began at 0300 hours (Friday morning) and ended at 1500 hours the following day. Participants experienced iterative testing throughout the session. Participants worked both in isolation and in three person teams to complete 40-min scenarios on the synthetic task described below. They also performed some basic cognitive tests. While participants were generally successful at remaining awake, occasionally proctors would have to encourage wakefulness through conversation or suggesting that a tired participant stand or walk for a while. Three participants (one team) were run during each experimental session.

Apparatus

Automated Neuropsychological Assessment Metrics (ANAM – Reeves, Winter, Kane, Elsmore, & Bleiburg, 2001) – ANAM is a collection of psychomotor and cognitive tasks developed to assess a range of cognitive capabilities. Two tasks were used for this study. *Continuous Processing* -participants determined whether the current number was the same as the previous value and memorized the current number for comparison to the next value. If the two numbers matched the left mouse button was pressed, the right mouse button was pressed if they did not match. *Mathematical Processing* -presented simple addition and subtraction problems containing two operands. Participants summed the three values and determined if the result was greater than (right mouse) less than (left mouse) 5. A number of metrics are supplied by the software for both tests, however; in this paper only throughput (1/mean response time to correct responses x 60 – giving responses per minute) will be reported. Both tests required approximately 3-min to complete.

Activity Log – Participants recorded their work and sleep times for three days prior to each experimental session.

Synthetic Command and Control Task -C^3STARS (C^3STARS for Command, Control, and Communication Simulation, Training and Research System) represents the roles, responsibilities, and task demands of a team of AWACS air battle managers (ABMs). This job was chosen for the task because it contains the core elements of command and control teams (resource management, resource assignment to tasks, coordination of responses) and could operate in either a hierarchical or flat structure. For this study, individual and team versions of C^3STARS were used.

Team C^3STARS Task -The team is composed of three individuals each performing a unique and necessary function for the team. The three roles are (1) Strike, (2) Sweep, and (3) Intelligence, Surveillance, and Reconnaissance (ISR). These three roles contain the functions sufficient to accomplish the team goal of destroying hostile ground missile targets (Surface to Air Missile sites – SAMs). The Strike role controls assets which are capable of jamming SAMs (i.e., prevent SAMs from 'seeing' an aircraft in close proximity or behind the jammer) and destroying SAMs (i.e., bombers). The Sweep role directs air-to-air assets (i.e., fighters) which are capable of defeating hostile aircraft. The ISR role controls information gathering aircraft (i.e., UAVs – unmanned aerial vehicles) and "tankers" capable of refueling other aircraft.

In this version of C^3STARS, the ISR role was intentionally constructed to be the least stressed. That is, to have the fewest activities to perform. This was done to allow for asset transfers between the other two roles and ISR. Transfers were the primary mechanism by which the team could reallocate workload. Strike bombers, once having expended their bombs, could be transferred to either Sweep or ISR for use in air-to-air protection. If Sweep was engaged in several areas and having difficulty tracking all the battles, they could transfer the fighters in one fight to ISR and let ISR manage that engagement.

Individual C^3STARS Task -While the individual task has the same goal, the same types of controllable resources, and the same types of hostile entities as the team task; there were two major differences. First and most important, all three roles (Strike, Sweep, ISR) were performed by a single person in isolation. Second, the total number of entities in the simulation was reduced by about 60%. In other respects the individual task scenario was similar to the team task scenario. The individual task required increased task knowledge on the part of the operator compared to the team task. However, all the coordinating activities were moved from external behaviors to internal activities. Thus explicit coordinating activities were no longer required. In retrospect, this reduced communication and coordination burden appeared to have resulted in making the individual task “easier” than the team task.

C^3STARS generates a host of performance measures. For this report however, for both the team and individual version, the outcome measures will be limited to two outcome measures and two process measures. The outcome measures are the number of friendly aircraft attacked and the number of air targets engaged. The process measures are the number of information windows opened (IWO) and the number of picture changes (PIX). The outcome measures represent two of the core functions required to accomplish the mission, while the process measures indicate behaviors concerned with information gathering and awareness of the battle area. The team measures are aggregated across team members and thus will be larger than the values for the individual measures. Of all the measures presented at the team level, number of friendly aircraft attacked requires the most cooperation amongst team members (resources controlled by two operators are required for this to occur).

Results

Prior to analysis of the experimental data, Student’s t-tests were performed on each dependent measure testing for changes from baseline to recovery. Significant improvements were seen for the majority of the dependent measures (see Table 1). Such learning effects will mask, to varying degrees, any fatigue effects. Consequently, the decision was made to adjust the data for the learning trends prior to analysis. For each individual (or team) the difference between baseline and recovery was calculated. Each trial, except for the first and last, was then adjusted by adding the appropriate proportion of that difference (e.g., for the third experimental trial of the team data 3/5 of the difference was added to the original value).

While this linear adjustment is conservative according to learning theory, which would predict more learning on earlier trials in a sequence (exponential improvement), it was used to guard against overestimating the effects of learning.

A repeated measures analysis of variance (ANOVA) was performed on the adjusted data of each dependent measure to test for changes over time. When the result was significant, post-hoc comparisons were made between each trial and baseline using simple effects tests. To quantify and compare effect sizes, partial Eta squared (ηp^2) was calculated for each ANOVA and subsequent t-tests. For tables 2 through 4, numbers in each cell represent the mean and standard deviation (in parenthesis); ^{h} indicates Huynh-Feldt adjustment; * indicates the mean was significantly different from baseline mean ($p<.05$, post-hoc 1-tailed t-test); ηp^2 = effect size and; data were adjusted for learning effects before analysis following the method mentioned above.

ANAM Results / Confirmation of the Fatigue Model

Continuous Processing Task Throughput – A significant time effect was observed. Performance on this task was well maintained through Day 2 23.00hr after which performance decreased significantly and remained depressed for the remainder of the experimental session (see Table 2). For example, ηp^2 for changes in throughput (i.e., baseline to any specific trial) remained below .03 through Day 2 23.00hr and then increased to .35-.53 for the remaining trials.

Mathematical Processing Task – A significant time change was again present for throughput. Unlike Continuous Processing, significant performance decrements began at the first experimental trial. While following the typical circadian variation, performance remained below baseline throughout (Fig 1). ηp^2 was .18 by the first trial (Day 2 05.30) and ranged from .29 to .61 thereafter.

Table 1. Baseline (Day 1, 17.30hr) vs. Recovery (Day 4, 16.00hr)

Test	Variable	Mean (Standard Deviation)			Np2	Student's t-test (one-tailed)	
		Baseline	Recovery	Change		t(df)	p
Continuous Processing	Throughput	114.2 (19.6)	129.9 (24.0)	15.7 (11.3)	.67	7.52 (28)	**<.001**
Math	Throughput	39.5 (8.9)	41.5 (11.7)	1.9 (5.7)	.11	1.89 (29)	**.035**
Individual C3STARS (Outcome Measures)	Friendly Aircraft Attacked	2.0 (1.6)	1.2 (1.1)	-0.8 (1.7)	.16	-2.36 (29)	**.013**
	Air Targets Engaged (22 possible)	21.1 (3.3)	21.6 (4.7)	0.5 (4.0)	.02	.68 (29)	.252
Individual C3STARS (Process Measures)	IWO	133.5 (55.2)	127.8 (57.5)	-5.7 (30.4)	.04	-1.02 (29)	.158
	PIX	717.5 (285.7)	750.7 (349.0)	33.2 (269.0)	.02	.68 (29)	.252
Team C3STARS (Outcome Measures)	Friendly Aircraft Attacked	12.3 (3.8)	9.7 (4.3)	-2.6 (3.9)	.34	-2.13 (9)	**.031**
	Air Targets Engaged (42 possible)	31.1 (5.5)	36.9 (3.1)	5.8 (5.7)	.53	3.20 (9)	**.006**
Team C3STARS (Process Measures)	IWO	380.6 (107.3)	393.1 (125.2)	12.5 (34.4)	.13	1.15 (9)	.140
	PIX	1789.8 (559.8)	2273.1 (879.1)	483.3 (465.0)	.55	3.29 (9)	**.005**

Table 2. Individual ANAM–Descriptive Statistics and ANOVA Results

Test/Variable (day-hour)	Time 1-14.00	2-04.00	2-10.00	2-16.00	2-22.00	3-04.00	3-11.00	3-13.00	ANOVA test of time effect MSE	F (df)	p	ηp2
Continuous Processing (TP)	114.2	119.3	112.9	115.6	115.9	101.7*	97.1*	100.0*	165.7	19.29h	**<.001**	.41
	(19.6)	(21.3)	(23.5)	(22.9)	(20.3)	(21.5)	(23.2)	(23.1)		(5,130)		
Math (TP)	39.5	37.6*	34.4*	36.3*	35.6*	32.7*	34.3*	35.2*	26.0	8.26h	**<.001**	.22
	(8.9)	(8.7)	(8.2)	(8.8)	(8.2)	(9.0)	(8.9)	(8.7)		(4,128)		

Complex Individual Performance

Significant time effects were seen for both outcome measures and both process measures. For all of the measures, there was a significant reduction in performance at Day-3 06.00hr (see Table 3). Partial Eta squared values for this change were: .50 for IWO, .15 for Pix, .31 for ATE, and .25 for FAA. In addition FAA, and ATE (see Fig 2) showed earlier reductions (Day-2 18.00). Generally, performance rebounded at the final trial (Day-3 13.00).

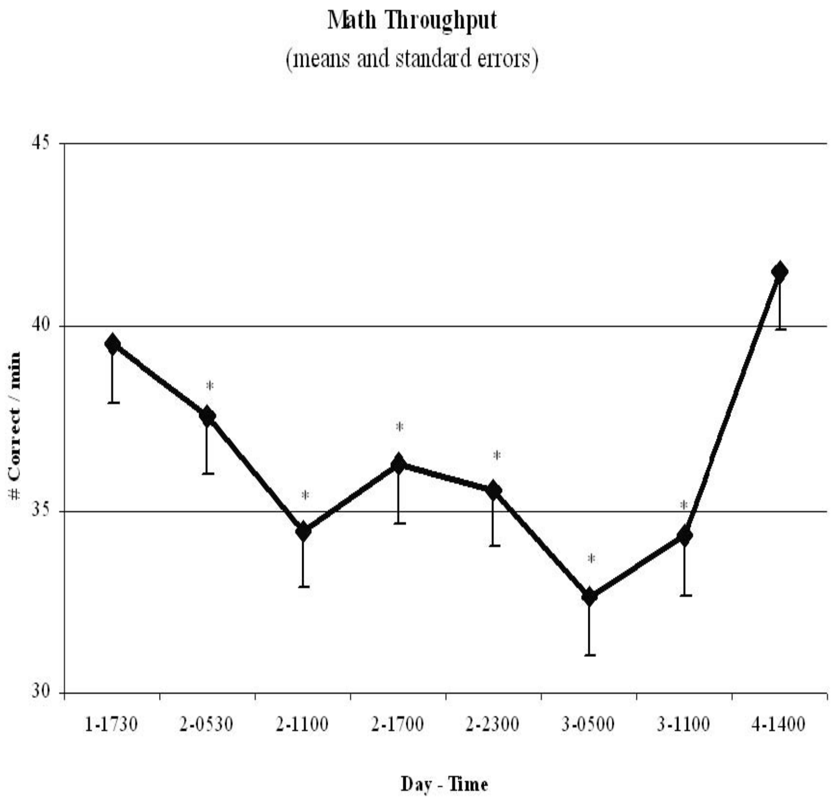

Figure 1. ANAM Math Results Over Time

Table 3. Individual CSTARS—Descriptive Statistics and ANOVA Results

Type of Measure	Variable	Time (day-hour)					ANOVA test time			
		1-18.00 (baseline)	2-06.00	2-18.00	3-06.00	3-13.00	MSE	F	p	ηp2
Outcome	Friendly Aircraft Attacked	1.8 (1.5)	1.4 (1.5)	2.4* (1.8)	2.9* (2.2)	2.2 (2.2)	1.70	4.39 (4,92)	**.003**	.16
	Air Targets Engaged	21.5 (3.3)	22.0 (3.3)	19.8* (2.8)	18.7* (4.6)	20.7 (5.4)	13.58	4.60 (3,64)h	**.007**	.17
Process	IWO	131.0 (55.7)	122.5 (67.3)	125.6 (63.2)	108.2* (67.5)	124.3 (64.7)	624.80	3.72 (3,69)h	**.015**	.14
	PIX	700 (303.1)	746.7 (315.2)	785.8 (325.6)	619.9* (241.9)	692.4 (333.2)	21691.3	4.32 (4,92)	**.003**	0.16

Complex Team Performance

Few team performance variables appear to be affected by fatigue (see Table 4 & Fig 2). Only one process measure, Pix, showed a significant effect of time. Pix counts decrease significantly at the Day-3 06.00hr trial, ηp^2 =.46.

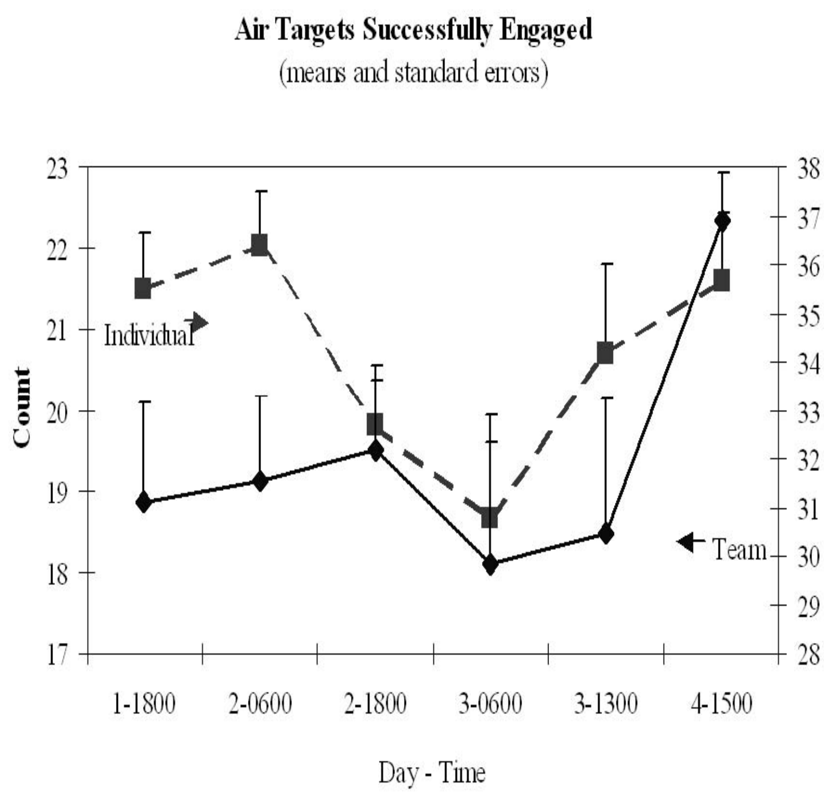

Figure 2. Individual and Team C3STARS

Table 4. Team CSTARS —Descriptive Statistics and ANOVA Results

Type of Measure	Variable	Time (day-hour)					ANOVA test time			
		1-16.00 (baseline)	2-04.00	2-16.00	3-04.00	3-10.00	MSE	F (df)	p	Np2
Outcome	Friendly Aircraft Attacked	12.3 (4.3)	13.8 (3.1)	12.7 (5.3)	13.6 (5.8)	12.5 (6.3)	14.95	.39 (3,18)h	.731	.05
	Air Targets Engaged	31.1 (5.7)	31.5 (5.0)	32.2 (5.0)	29.8 (8.7)	30.5 (7.8)	27.86	.24 (4,28)	.914	.03
Process	IWO	389.3 (111.6)	372.3 (99.4)	387.0 (101.3)	350.1 (109.7)	358.6 (116.1)	1932.40	1.22 (4,28)	.325	.15
	PIX	1846.8 (613.9)	1827.4 (509.2)	1765.6 (590.1)	1615.8* (433.9)	1458.4* (641.6)	72884.91	2.95 (4,28)	**.038**	.30

Discussion

As anticipated, performance on the individual simple cognitive tasks followed the well-established pattern combining circadian and sleep deprivation effects for cognitive metrics (Hockey, 1986). This finding provides support for the efficacy of the experimental manipulation (i.e., keeping people awake for the specified schedule produced negative performance changes). The observed effect sizes for the simple performance data were modest (CPT ηp^2 =0.24; Math ηp^2 =0.19). Thus, while successful, the experimental manipulation was not overwhelming.

C^3STARS individual performance showed the same trends as the more basic tests. All of the dependent measures from this task showed significant changes over time. These findings, support the idea that complex performance can be negatively impacted by fatigue, and proved that C^3STARS' is a sensitive measure of fatigue.

Complex team performance generally did not degrade with the level of sleep deprivation used in this study. Of the four measures, only Pix showed a significant time effect. Neither of the outcome measures evinced effect sizes comparable to those seen at the individual level. While power was reduced at the team level relative to the individual level (i.e., team sample size is one third of individual), it is unlikely that significant time effects would have been observed even if the team sample size were increased. It was anticipated that reduced power might lead to non-significant results at the team level but that trends would be present indicating a deleterious impact of fatigue. However, this is not the case for the outcome measures. As can be seen from the data, teams continued to learn throughout the experimental session. One explanation for this is, while they understood the taskwork requirements (as evidenced from their individual performances); they continued to develop teamwork skills (anticipatory behaviors and strategies).

There are several potential explanations operating at different levels which could account for teams performing less poorly under fatiguing conditions than individuals. It is possible that inter-individual communication may produce a stimulating effect which may in turn reduce the amount of perceived effort on the part of team members when compared to individual performance. The debrief and predictive pre-brief may increase a sense of accountability beyond what is experienced in the individual task and reduce social loafing (Latane, Williams, & Harkins, 1979), resulting in increased motivation for the team task. A similar motivational increase may constrain satisficing, maintaining performance expectations and resulting in increased expenditure of effort at the team level. It may be possible that even with a similar level of satisficing and general brain activation (i.e., stimulation) a team is simply more adaptable and better able to cope with the effects of fatigue due to redundancy and mutual assistance capability. Future studies of teams and sleep deprivation should include additional subjective metrics, like estimates of effort and workload, to disentangle these theories.

Many more outcome measures were collected from C^3STARS than are reported in this paper. It is intended to present many of these measures in a future publication. As well, it is planned to perform several further analyses of the data. For example, to examine individual participants and teams to determine if there are relationships between baseline performance level, learning, and the impact of fatigue. Finally, analyses will be made relating individual information (e.g., personality traits, amount of pre-session sleep) with their performance in the experimental session.

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