The effects of light exposure on flight crew alertness levels to enhance fatigue risk management predication models

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Abstract:
Fatigue Prediction models are used as scheduling tools to manage risks associated with fatigue. They allow for proactive identification of possible hazards and the use of risk management tools to mitigate risks aspects of a Safety Management System (SMS). These tools provide ways for airlines to pre-determine which flights and schedules may have more risk and allow operators to intervene and proactively reduce risk when possible. This process allows the operator to identify inherent risk built into flight schedules to maximize alertness. This adds another layer to the operators' safety management systems. Current fatigue prediction models do not account for light/night effect on alertness levels. The effects of light on alertness have been well established and could be built into fatigue risk management systems. Recent research conducted by Brown et al., (2014) examined whether timed ocular light exposure could mitigate fatigue, reducing physiological, perceived and cognitive fatigue —to transform aviation alertness models [4]. The availability of this information opens up a new range of possibilities, making it possible to "build" light/dark effect into crew alertness models and scheduling tools to improve aviation safety, crewmember health and manage risk.

Keywords: Light Therapy, Fatigue Risk Management Systems, Aviation, Fatigue Countermeasure, Risk

1. INTRODUCTION

Fatigue is a threat to aviation safety because of the impairments in alertness and performance it creates. It has significant physiological and performance consequences because it is essential that all flight crewmembers remain alert and contribute to flight safety by their actions, observations, and communications [13, 32, 9, 34]. According to the National Sleep Foundation's (NSF) 2012 Sleep in America® poll "Pilots and train operators are most likely to report sleep-related job performance and safety problems [24]." One in five pilots (20%) admits that they have made a serious error and say that they have had a 'near miss' due to sleepiness and report car crashes due to sleepiness at a rate that is six times greater than that of other workers. Sleep experts at the National Sleep Foundation (2012) report "The common thread running through all of it is fatigue, which has caused crewmembers that in cases of emergency were just so numb they couldn't respond instantly to a tragedy at hand [24]." Recent fatal accidents caused by fatigue have brought out several serious concerns for the Federal Aviation Administration (FAA) and the NTSB [25, 26].

One poignant example of how fatigue is a fatal causal factor in aviation is the crash of Colgan flight 3407, which crashed in Buffalo, New York, on February 12, 2009. According to the National Transportation Safety Board (NTSB) report (2010), "the pilots' performance was likely impaired because of fatigue [25]." The first officer had commuted all night from Seattle on a Fed-EX cargo aircraft and had been awake for 30 hours before the crash. The Captain had also commuted and slept in the crew room before signing in for the flight. This time commuting to work is not included in duty time, which increases the crewmembers 'time since awake' [10]. Research shows that after 16 hours of 'time since awake'; performance is similar to someone who is legally drunk [13, 34].

Brown et al., (2014) notes there have been numerous occurrences of pilots falling asleep while on duty. Examples cited include: the evening of October 21, 2009, a Northwest Airlines Airbus A-320, over flew its destination by 150 miles before the pilots' re-established contact with air traffic controllers. The NTSB released a report of its investigation into a Go Airlines which flew past the Hilo airport because the two pilots fell asleep. A similar incident in June, 2008 occurred when New Delhi, India: An AIR India flight headed for Mumbai overshot its destination 359 miles and was halfway to Goa before its dozing pilots were woken out of a deep slumber by air traffic control [8, 11]. In addition to falling asleep while flying, sleep inertia has also been cited as a factor in fatal accidents. On 22 May 2010, an Air India Express Boeing 737-800 overran the landing runway at Mangalore when attempting a go around. A factor in respect of the approach, landing and failed go around attempt was cited as the effect of 'sleep inertia' on the Captain's performance and judgment after a prolonged sleep en-route.

Fatigue in aviation is not limited to pilots; research has identified key findings concerning fatigue in the pilot and flight attendant occupation, where sleep deprivation and disruption of circadian rhythms were known to occur [32, 27]. Flight Attendant fatigue continues to be a chronic problem, which can jeopardize safety and security [8, 9].

Fatigue related risk is not isolated to aviation [14]. Fatigue is a prominent risk factor cited in rail, maritime, nuclear, and medical occupations. On April 17, 2011, about 6:55 a.m. central daylight time, eastbound BNSF Railway coal train (BNSF 9159 East) was travelling about 23 mph, and collided with the rear end of standing BNSF Railway maintenance-of-way equipment train near Red Oak, Iowa. The collision resulted in the derailment of 2 locomotives and 12 cars. As a result of collision forces, the lead locomotive's modular crew cab was detached, partially crushed, and involved in a subsequent diesel fuel fire. Both crewmembers on the striking train were fatally injured. Damage was in excess of $8.7 million [26].

The NTSB determined that the probable cause of the accident was the failure of the to comply with the signal indication requiring them to operate in accordance with restricted speed requirements and stop short of the standing train because they had fallen asleep due to fatigue resulting from their irregular work schedules and their medical conditions. Train crew fatigue was identified by the NTSB as safety issue in the fatal accident [26].

2. FATIGUE RISK MANGEMENT IN AVIATION

While the aviation industry provides the safest form of transportation in the United States, the industry continues to have accidents which may be prevented with risk mitigation. The FAA encourages certificate holders to develop a safety management plan (FAA, AC 120-92) defining protocol to introduce operators to aid in the development of safety management plans to manage hazardous conditions to mitigate risk.

A hazard is a condition that is a prerequisite of an accident or incident. The FAA (AC 120-92), defines such hazards as: any existing or potential condition that can lead to injury, illness, or death to people; damage to or loss of a system, equipment, or property; or damage to the environment. A risk assessment tool should allow operators and pilots to identify risk in order to pinpoint operational areas of risk so that operators can determine an acceptable level of risk for flights based on the type of operation, environment, aircraft used, crew training, and overall operating experience. The FAA provides a risk assessment tool as an aid to operators (AC 120-92). Each operator can use the tool as published or to modify it as needed for their own operations, to establish a "risk number" for each flight. This risk number can be used to control risk before a flight takes place. The risk assessment tool provided in the FAA advisory circular (AC 120-92), assigns a risk value to various flight conditions such as night landing, crosswind, and low visibility. Although the tool does take flight crew hours and experience in to account, it does not assign a value of risk to the fatigue level crew may be experiencing. Fatigue risk management systems can be integrated into current safety management system plans to mitigate fatigue related risk.

Fatigue Risk Management Systems, defined by ICAO, allow for continuous monitoring and maintaining fatigue related safety risks, based on scientific principles and knowledge, as well as operational experience that aim to ensure relevant personnel are performing at adequate levels of alertness. A robust fatigue risk management plan adds another protective layer to the overall safety management plan, and can use scientific models to build crew schedules. The scientific models look at individual risk to build mitigating crew schedules, which analyze both crew and flight alertness risk. Building alertness into a schedule with scientific based models can decrease fatigue risk [1].

On example is the FRMS utilized by easyJet airlines, which includes a crew fatigue reporting mechanism with associated feedback, procedures and measures for assessing and monitoring fatigue, procedures for investigating related incidents, evaluation, and a competency based education and awareness program [33].

3. ALERTNESS MODELS

In order for the fatigue management to be effective, behavioral alertness must be considered. Alertness models such as, the Boeing Alertness Model (BAM) is a bio-mathematic model to predict alertness, and risk [1, 18, 19] as well as provide fatigue mitigation alternatives for crew. This allows airlines to take into consideration some important quality of life issues including commuting when constructing their crew schedules. Estimated crew vulnerabilities such as predicted fatigue or lack of experience can further be combined with external threat factors such as crosswind and airport difficulty into an overall risk index used during crew scheduling to proactively reduce risk.

Built on the Boeing Alertness Model (BAM), Boeing and Jeppesen developed tools for allowing better management of alertness and fatigue with mathematical modeling tools. BAM has been proven successful in analyzing the levels of alertness and fatigue among both flight attendants and pilots [1, 19]. There is potential for numerous benefits when utilizing such fatigue risk management tools which can ultimately improve safety within the industry. Built on the Boeing Alertness Model, Jeppesen developed a fatigue risk management application, called 'CrewAlert'. CrewAlert is the first iPhone application designed specifically to help airlines and their crews manage alertness and fatigue [20]. The application allows airlines to track fatigue trends, construct crew pairings and schedules, using problematic scheduling models, to construct less fatiguing schedules for flight crew 18, 19]. This has been evident in crew scheduling with airlines such as Finnair [33].

4. EFFECT OF LIGHT ON BEHAVIORAL ALTERNESS

A review of literature on the alerting effect of light shows it to be a potentially useful countermeasure where conditions allow its use [2, 3, 5, 6, 7, 8, 11, 12, 28]. Bright white or blue light treatments may applied to real aviation occupational settings such as: crew check-in rooms, at home before flight schedule, hotel layovers, air-traffic control break rooms, and possibly aircraft galleys [8, 9, 11]. Several studies have noted that a combination of countermeasures such as, napping or caffeine combined with bright light —have a more pronounced effect compared to a single countermeasure [14, 15, 16, 21, 22, 35].

Recent studies conducted by Steven Lockley, PhD, neuroscientist at Brigham Women's Hospital, unveil how light impacts the brain and open up a new range of possibilities for using light to improve human alertness, productivity and safety. Light has been well established to improve alertness in night workers and has obvious safety benefits; however, day shift workers may also benefit effects of light [23, 6, 7]. This is relevant to the short haul crewmembers with multiple legs as well as, long haul flight crew.

Light exposure, particularly blue light, has being recognized as a potent mean to stimulate alertness and cognition in young individuals [4, 22, 31]. This is evident in previous studies which have demonstrated short-wavelength sensitivity for the acute alerting response to nocturnal light exposure [12, 15, 22]. Researchers Shadab et al., (2014) assessed daytime spectral sensitivity in alertness, performance, and waking electroencephalogram (EEG). The study reports daytime and nighttime 460-nm light exposure significantly improved auditory reaction time ($P < 0.01$ and $P < 0.05$, respectively) and reduced attentional lapses ($P < 0.05$), and improved EEG correlates of alertness compared to 555-nm exposure. Moreover, nighttime 460-nm exposure improved alertness to near-daytime levels [31].

A 1997 study titled 'Combination of bright light and caffeine as a countermeasure for impaired alertness and performance during extended sleep deprivation' [35] looked at the effects of four conditions (Dim Light-Placebo, Dim Light-Caffeine, Bright Light-Placebo and Bright Light-Caffeine) on alertness, and performance. The three treatment conditions, (compared to the Dim Light-Placebo condition), enhanced night-time performance. Notably, the Bright Light-Caffeine condition was able to overcome the circadian drop in performance for most tasks measured [35].

5. EFFECT OF BLUE LIGHT

The function of shortwave blue light (460nm) to improve alertness and cognitive function "via non-image forming neuropathways has been suggested as a non-pharmacological countermeasure for drowsiness across a range of occupational settings [2]." As shown in research conducted by Leger et al., (2008), "bright light could be an effective countermeasure" and warrants further study [21].

Beaven and Ekstrom (2013) reported that both the caffeine only and blue light only conditions enhanced accuracy in a visual reaction test requiring a decision, and an additive effect was observed with respect to the fastest reaction times. However, in a test of executive function, where a distraction was included, caffeine exerted a negative effect on accuracy. Furthermore, the blue light only condition consistently outperformed caffeine when both congruent and incongruent distractions were presented. "Overall, blue light and caffeine demonstrated distinct effects on aspects of psychomotor function and have the potential to positively influence a range of settings where cognitive function and alertness are important [2]". Researchers Cajochen et al. (1999) also showed measurable increases in subjective alertness and reductions in slow eye movements, with short wavelength (blue) light appearing to have the greatest alerting effect [12].

Researchers from Brigham and Women's Hospital (BWH) teamed with George Brainard, Ph.D, professor of neurology at Thomas Jefferson University in Pennsylvania and Harvard Medical School which reported that exposure to short wavelength (460nm) blue light during the biological night directly and immediately improves alertness and performance [5, 6, 7]. The study subjects exposed to blue light consistently rated less sleepy, had quicker reaction times, and had fewer lapses of attention during the performance tests. Changes in their brain activity patterns indicated a more alert state [5].

6. The Effect of Blue Light on Pilot and Flight Attendant Behavioral Alertness Study (2014)

Drawing on successful research using light therapy to improve behavioral alertness [12, 21, 22], Western Michigan University studied effects of blue light in the aviation occupation field setting. The study was funded by the Western Michigan University (Kalamazoo, Michigan, USA) FRAACA award, to look at the effects of blue light (460nm) in the occupational setting with flight crew members. The study aimed to investigate the efficacy of blue light therapy to improve alertness in flight crew-members. Western Michigan University, College of Aviation, Jeppesen (a Boeing Company), Nature Bright Company, Airline participants, and a leading sleep researcher Schoutens, A.M.C. of FluxPlus, BV, The Netherlands, collaborated to examine whether timed blue light could improve flight crewmember alertness and mitigate cognitive fatigue— as seen with gold medal Olympic athletes to improve performance [11].

<u>Methods</u>

Fourteen flight crew members, working as pilots or flight attendants, participated in the 30 day study under the Western Michigan University HSIRB approved protocol. All participants were nonsmoking, active flight crewmembers. The crewmembers were based in Sweden and maintained flight schedules to the Mediterranean and the Canary Islands, as well as long-haul flights to Thailand, India and Vietnam. Each participant signed an informed consent document and attended a two hour training session on the use of the light and actigraphy band. Each participant was assigned a confidential code and completed the Morningness-Eveningness Questionnaire (MEQ), a self-assessment questionnaire [17], to measure their peak sleepiness and alertness time (diurnal type). The MEQ was used once at the beginning of the testing period to assess the habitual and preferred weekday and weekend clock times of the participants. The MEQ is a self-report instrument that consists of questions in which the participant indicated their preference using a 4-point Likert Scale.

During the 30 day study, the crewmembers wore actigraph wrist bands to record sleep/wake behaviors, and recorded self-assessed levels of sleepiness with the Karolinska Sleepiness Scale (KSS) daily. Daily self-assessed fatigue [32] was recorded using the Samn-Perelli Fatigue Scale (SP), and they completed daily psychomotor vigilance tests (PVT) [4]. The iOS users recorded daily data on their iPhone via the Jeppesen CrewAlert Lite application. On the third and fourth weeks, the flight crew-members were exposed to a 30 minute daily intervention with blue light short wavelength (460nm) light therapy, using a small portable light unit (shown in Figure 1). The crewmembers were instructed not to use the light during flight operations to ensure the study would not interfere with the safety of flight during normal long haul flight schedules.

Actigraphy wrist bands and the Karolinska Sleepiness Scale (KSS) were used for detection of circadian rhythmicity in neurobehavioral variables. Actigraphy and KSS have garnered successful results been reported in studies with a wide array of subjective measures of alertness and fatigue [22, 31, 12, 2, 3]. The KSS is used to obtain subjective alertness and mood assessed with 9-digit rating scales, and the visual psychomotor vigilance test (PVT) to measure vigilance (response time in milliseconds and lapses) [4]. The first two weeks of the study recorded the baseline pre-light intervention, followed by two weeks of daily, 30 minute light intervention followed by the actigraphy, KSS, SP, and PVT recordings, in addition to the control group without light intervention for 30 days [11].

<u>Equipment</u>

Nature Bright Company provided 20 Square One® rechargeable, portable, lightweight, wake-up lights which weighed less than 2 lbs. The Square One light provides blue (λmax = 465 nm) light intervention and is currently one the smallest light therapy devices on the market, with an advanced optical lens and a wakeup light alarm feature. The Square One (Figure 1.) was selected due to the small portable size, ideal for crewmembers, as it was easy to place in a flight bag, handbag or luggage [11].

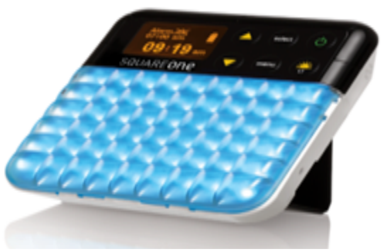

Figure 1. Nature Bright Square One® rechargeable portable light [http://www.naturebright.com/]

CamNTech MotionWatch 8 actigraphy wrist band with a tri-axial digital accelerometer was worn for 30 days by all participants. Actigraphy has been used in studies to measure sleep/wake patterns for decades [11]. The advantage of actigraphy over traditional polysomnography (PSG) is that actigraphy is non-invasive (a water proof watch band) and can conveniently record continuously for 24-hours per day for days, weeks or even longer.

Figure 2. CamNTech MotionWatch 8 http://www.camntech.com/

Sleep analysis plots downloaded from the Motion8 band, coupled with specialized software used to quantify the intensity and duration of daily physical activity. This data was analyzed to identify irregular activity patterns for assessment of sleep quality. Individual, daily sleep efficiency and sleep bouts were used to look for correlations with the KSS, SP, and PVT results. These data point to relationship between improved sleep efficiency and decreased sleep boats within subject post light interventions [11]. Results garnered from these data may be valuable to build light effect into fatigue model and alertness models. The band also measured the amount of lux each participant was exposed to during the actigraphy period.

<u>Jeppesen Crew Alert (lite) iOS Application</u>

Data collection was through the (iOS) Boeing Alertness Model (BAM) application called Jeppesen CrewAlert Lite, (Figure 3.) which can be used anywhere in the world with an Apple iPhone, iPod, or iPad device [19]. The Jeppesen/Boeing CrewAlert (lite) tool was provided to the study with access and data extraction from Jeppesen. The crew alert application is an easily accessible interface to KSS, PVT and SP scores, integrated with the Boeing BAM model. BAM is a bio-mathematical model of alertness, which has been developed from recent science [1, 18, 19 20]. BAM considers work and sleep schedule, and predicts alertness based on physiology and performance data [18, 19, 20].

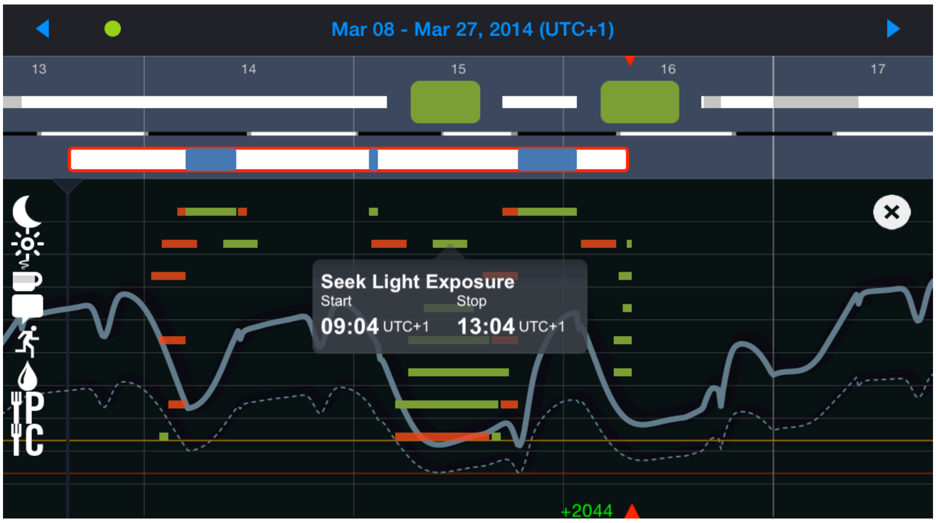

Figure 3. Jeppesen CrewAlert [http://ww1.jeppesen.com/Application]

The Jeppesen CrewAlert fatigue risk management tool is used for quantifying current fatigue levels connected to certain flights or scheduling patterns initiated by elevated fatigue reports [18, 19]. Following the data upload de-identified, alertness assessments, are generated along with a visualization of the collected data with alertness predictions side-by-side, in a .csv file for easy correlation and other analysis [18]. The report with crew's scheduled activities was not utilized in this study, as the scope was looking at the effect of light on their KSS, SP, PVT, and sleep efficiency.

Results

A repeated measures multivariate analysis of variance (MANOVA) was conducted, using IBM SPSS Statistics 20 software, to test the intervention effect of blue light (IV) on both flight and cabin crew alertness, measured by the 4 DVs; KSS, SP, PVTR, and PVTL [11].

A one-way MANOVA revealed a significant multivariate within-subject main effect for time (pre and post light intervention), Wilks' $\lambda = .609$, $F(4,55) = 8.843$, $p < .001$, partial eta squared = .391, and the power to detect the effect was .999. The analysis also revealed a significant multivariate between-subject main effect for position (pilot/flight attendant), Wilks' $\lambda = .506$, $F(4,55) = 13.429$, $p < .001$, partial eta squared = .494, and the power to detect the effect was 1.000.

The results show that there was a significant difference in alertness between pre-intervention and post-intervention for each crew member, and that 39.1% of the variance is explained by time (pre/post intervention). There is also a significant difference in alertness between flight crew and cabin crew, and 49.4% of the variance is explained by position (flight/cabin crew) [11].

Figure 4 shows that for the measure Karolinska Sleepiness nine point Scale (KSS), there is a similar intervention effect for both pilots and cabin crew, but there is a difference in the estimated marginal means related to crew position (1 = pilot and 2 = cabin crew). It is clear that both pilots and flight attendants had a decreased self-assessed sleepiness; however, the reason for the difference in the estimated margin of means based on crew position was not evident.

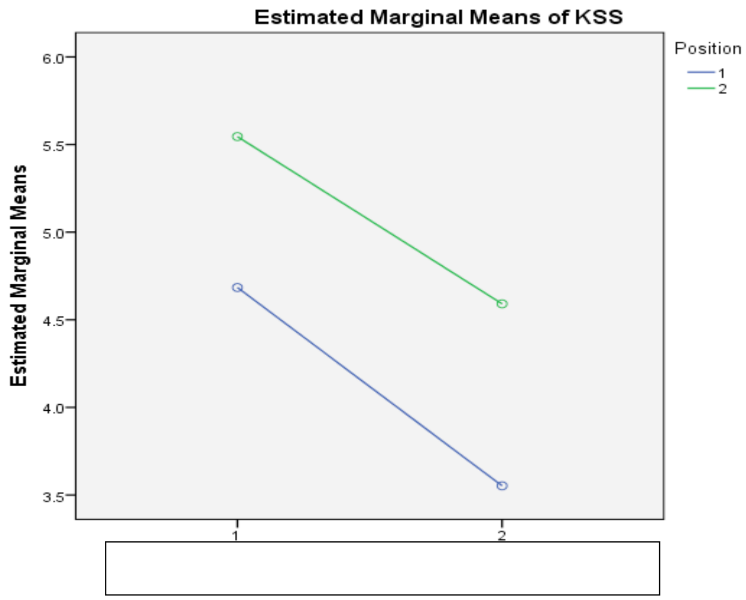

Figure 4 KSS Sleepiness Pre/Post Intervention Marginal Means by Position

The Karolinska Sleepiness Scale (KSS) is a 9-point Likert scale based on a self-reported, subjective assessment of the subject's level of drowsiness at the time [16] where 1 = extremely alert and 9 = extremely sleepy/fighting sleep. The independent measure derived from the KSS Checklist was self-rated sleepiness. Higher scores indicated a higher level of subjective sleepiness. KSS has been used widely, particularly for describing changes over time within subjects [16].

Figure 5 shows that for the measure Samn-Perelli [30] seven-point fatigue scale (SP), there is a larger intervention effect for cabin crew, but there is still a difference in the estimated marginal means related to crew position pre and post intervention (1 = pilot and 2 = cabin crew).

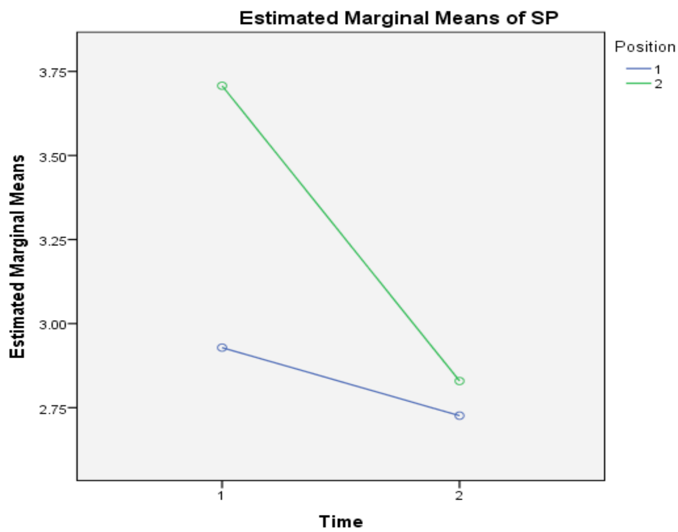

Figure 5. SP Fatigue Scale Pre/Post Intervention Marginal Means by Position

Subjective fatigue was assessed using the Samn-Perelli Fatigue Checklist [30]. The Samn-Perelli is a 7-point Likert scale, where 1 = fully alert/wide awake and 9 = completely exhausted, unable to function effectively. Higher scores indicated a higher level of subjective fatigue [30].

Vigilance was assessed with the Psychomotor Vigilance Test (PVT), a 5-minute iOS visual reaction-time task which evaluates sustained attention [4]. Participants were instructed to respond to the appearance of a visual stimulus by tapping a black bulls-eye target on the iOS screen as quickly as possible. During each 5-min session, visual stimuli appeared at variable intervals of 2–10 s. From each PVT trial, reaction times (RTs) were collected and 2 performance variables, average response time and number of lapses (i.e. failure to respond or RT > 500 msec) were extracted by Jeppesen Crew Alert.

Table 1. below shows the intervention means measure psychomotor vigilance test reaction time in milliseconds (PVTR). There is a significant positive intervention effect (reduced reaction time) for the cabin crew, but not significant for pilots. However, there is a difference in the estimated marginal means related to crew position (1 = pilot and 2 = cabin crew). Research suggests individual performance may differ between subjects [3], and can vary with gender and age [4]. Optimal performance on the PVT appears to rely on activation within the sustained attention and within the motor system [4]. According to Wright et al., (1997), PVT can also rely on work schedules, and sleepiness countermeasures such as naps, bright light, and caffeine [35]. Depending on the degree of sleep deprivation, “the fastest RTs on the PVT do not change or change only modestly relative to the well-rested state, and the slowest RTs can lengthen dramatically after sleep deprivation [4].

Table 1. PVTR Pre/Post Intervention Means by Pre and Post Intervention

PVTR_Without Light Mean RT	1 Pilot	369.87
	2 Cabin	438.36
	RT without Light	**394.98**
PVTR_With Light Mean RT	1	348.92
	2	420.36
	RT with Light	**375.12**

Figure 7. below shows that for the measure psychomotor vigilance test lapse rate (PVTL) there is a similar intervention effect for both pilot and cabin crew, however there is a difference in the estimated marginal means related to crew position (1 = pilot and 2 = cabin crew). PVT lapses are defined as a failure to react, or any reaction exceeding 500 milliseconds, and are often used as the primary outcome

measures of PVT performance [4, 11]. Research indicates the number of lapses during the psychomotor vigilance task is an objective measure of fatigue [4, 11].

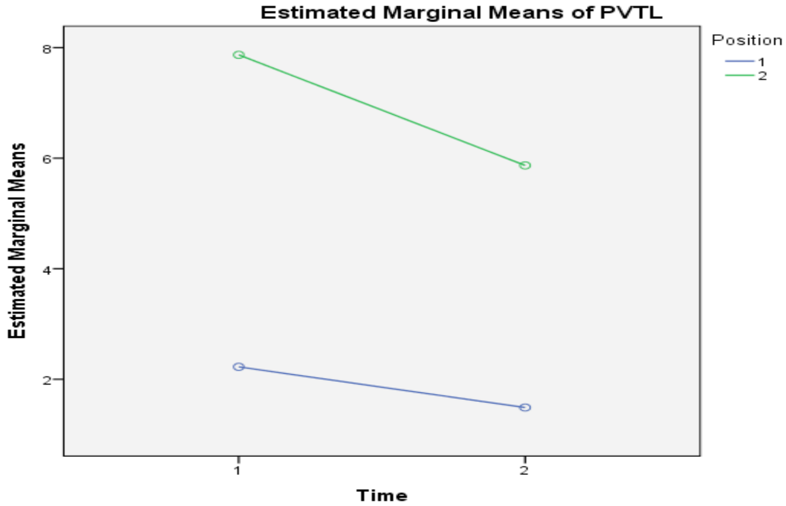

Figure 7. PVTL Pre/Post Intervention Marginal Means by Position

7. CONCLUSION

The benefits of light therapy extend well beyond aviation, and are often used with depression, dermatology, psychiatry, neurology and gerontology and work related issues such as, shiftwork and sports medicine (Dutch Olympic Swimming Team, TVM Ice -skating team, Dutch Olympic Committee). In addition to individual crewmembers using portable light units as a fatigue countermeasure, crewmembers can benefit from simple 'light stations' in crew check-in areas and light effect can be integrated into alertness models [11]. Expanding the limited body of scientific knowledge about light effect on alertness may allow us to integrate light/dark effect into alertness models, to improve fatigue management systems. With algorithms indicating peek and low times in the schedule we may be able to determine when and how long the crewmember should seek natural or artificial light beyond adjusting circadian rhythms.

Although natural light is not always practical in the aviation setting, portable small light weight units for flight bags and desktop light boxes placed in crew break areas, (10,000 lux, 17,000 Kelvin UV-Free lights which mimic a blue sky) could be effective. Operators can work with their flight surgeons and health departments to discuss these options. Educating crewmembers on the acute effect of light on their sleep, mood, and alertness is crucial, particularly as we look closer at the quality of life and sleep issues with crewmembers —such as sleep apnea. In addition to improved alertness, relief from seasonal affective disorder could also be a benefit- particularly in the dark winter months in areas such as Seattle, Norway, Sweden, Canada and Michigan.

Ideally an actual blue light would be integrated into the fatigue risk management application on the crewmembers phone; however, due to the low level of lux from a cell phone, science indicates such applications would not effective as we know it today. Although several applications claiming to give benefits of blue light therapy with an application download exist, they are not based on science considering the amount of lux emitted from a cell phone or tablet device. Perhaps the most feasible option with the current scientific knowledge available would include light effect built into mathematical models. The current frms application could work in conjunctions with small portable light nits to provide light intervention when appropriate, with circadian rhythm and phase shift considerations. Clearly, there is still a need for further research on the best ways to integrate specific timed light in the occupational setting, perhaps drawing on some of the innovate mood lighting for passengers in modern aircraft, and evaluations of the most appropriate spectrums. The CrewAlert Pro application from Jeppesen contains fatigue mitigation functionality proposing time intervals for light exposure/avoidance that potentially could combine well with usage of light boxes.

One area which may deserve further research is red light intervention —which may conducive to night flight deck operations. In a study conducted by researchers Levent, et al., (2013), at Rensselaer Polytechnic Institute shows that exposure to red wavelengths and levels of light has the potential to increase alertness. In most studies to date, the alerting effects of light have been linked to its ability to suppress melatonin [15, 22, 29]. However, results from other studies demonstrate that acute melatonin suppression is not needed for light to affect alertness during the nighttime [31]. Both short-wavelength (blue) and long-wavelength (red) lights increased measures of alertness but only short-wavelength light suppressed melatonin [31]. Melatonin levels are typically lower during the daytime and higher at night [15, 22, 29, 31]. Providing future research looks into the spectral sensitivity of alertness and how if it changes over the course of 24 hours, this would be helpful for building light into bio-mathematical alertness models. Current findings provided the scientifically valid underpinnings in approaching fatigue related safety problems in 24 hour transportation operations to mitigate risk [31].

Acknowledgements

the authors would like to express their gratitude for all of the airline participants who volunteered their time to participate in this study; participating Airlines and staff; Jeppesen, A Boeing Company; Tomas Klemets; Gregory A. Pinnell MD, senior AME, senior Flight Surgeon USAFR; Industry Aviation Human Factors Consultants, Jeanne Kenkel, Sherry Saehlenou, and Captain John Gadzinski; Light therapy researcher Toine Schoutens; Nature Bright Company, Western Michigan University and CamNtech. This study would not have been possible without your collaboration.

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