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# THE EFFECTS OF BRIGHT LIGHT INTERVENTION ON FLIGHT CREW BEHAVIORAL ALERTNESS AND COGNITIVE FATIGUE

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The study aimed to investigate the efficacy of bright light intervention to improve behavioral alertness and reduce cognitive fatigue in flight crew-members. During the four week study, crewmembers wore actigraph bands to monitor sleep behaviors. Self-assessed levels of sleepiness were recorded using the Karlosinska Sleepiness Scale (KSS), and self-assessed fatigue was measured using the Samn-Perelli (SP) fatigue scale. Participants completed psychomotor vigilance tests (PVT) to measure behavioral alertness. On the third and fourth weeks of the study, participants were exposed to short wavelength bright light (465nm blue) light intervention. The results show that there was a significant difference in alertness and cognitive fatigue 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).

Cognitive fatigue is a threat to aviation safety because of the impairments in alertness and performance it can create. 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 (Strauss, 2006). One poignant example which proved to be fatal for all onboard, was the crash of Colgan flight 3407, in Buffalo, New York, on February 12, 2009. According to the NTSB report (2010), “the pilot’s performance was likely impaired because of fatigue”. The first officer had traveled to work (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 traveled and slept in the crew room before the flight. This time traveling to work is not included in duty time, which increases the crewmembers ‘time since awake.’ Research shows that after 16 hours of ‘time since awake’ performance is similar to someone who is legally drunk. Additionally, there have been numerous occurrences of pilots falling asleep while on duty. These aircraft are operated by the autopilot, and are at risk of mid-air collisions, running low on fuel, impact into terrain, or being mistaken for hijacked aircraft and possibly intercepted or shot down, if no communications are established. 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 reduce cognitive fatigue.

## Countermeasures

Safety being the most important objective in aviation can be improved with effective countermeasures to reduce fatigue related errors. Countermeasures can be classified in two categories, preventative and operational. Preventive strategies are used before flying or between flights to reduce the effects of fatigue, sleep loss, and circadian disruption. Proper sleep hygiene, a nap (no longer than 45 minutes) before a flight schedule, hydration, nutrition, exercise, and in some cases -treatment for sleep apnea have all been cited as effective preventative strategies for flight crew. These techniques can help to decrease the likelihood of the crewmember starting the trip with a sleep deficit. Whereas, Operational strategies are used during flights to maintain alertness and performance include controlled timed napping, hydration, bright light, strategic use of caffeine, proper nutrition, short walks when able (flight attendants only), and in seat stretches for pilots. The need of a combination of napping and other countermeasures, to improve alertness has been demonstrated by, Garbarino et al., 2004; Gronfier et al., 2007. While operational countermeasures can be most effective when combined with other operational or preventative countermeasures, this study focused on the bright light intervention.

## Light Interventions

Alerting effects of light are tied to its suppression of melatonin, which is ordinarily released in the evening and night. Researchers Cajochen et al. (1999) showed measurable increases in subjective alertness and reductions in slow eye movements, with short wavelength (blue) light appearing to have the greatest alerting effect. There is also evidence that the alerting effects of light are independent of the time of day, leading to the possibility of employing light during the daytime to improve alertness and performance in individuals impaired due to prior sleep deprivation (Cajochen, 2007). Capitalizing on the immediate, direct alerting effects of light for flightcrew is particularly useful because the flight-deck environment with its high automation level, “limited opportunities for physical activity or social interaction, steady background noise, and low nighttime light levels creates a setting ripe for boredom, complacency, attention lapses, sleepiness, and performance decrement” (Caldwell, 1997). As shown in research conducted by Leger (2004), “bright light could be an effective countermeasure” and warrants further study. Despite the widespread use of light intervention in competitive sporting environments, the possible impact of blue or bright light therapy (ocular therapy) in aviation has received little attention, compared to caffeine.

A review of literature on the acute alerting effect of light shows it to be a potentially useful countermeasure where conditions allow its use. Light treatments may be easy to apply in 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. Several studies have noted that a combination of countermeasures have a more pronounced affect compared to a single countermeasure (Wright JR, K., Badia, P., Meyers, B., and Plenzler , 1997). Based on this hypothesis, Léger et al., (2004) designed a preliminary study to test the effects of combination of napping and bright light pulses in a pilot group of shift workers. This study used short pulses (10 min) of 5000 lux white light, combined with naps (Leger et al., 2004). Both the number and the duration of the episodes of sleepiness were reduced by the intervention” (Leger et al., 2004). Beaven and Ekstrom reported (2013) 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. Research also suggests that natural light has the same beneficial affects providing the crewmembers have the ability to receive natural light treatment in the operational setting-which makes the use of small lightweight portable artificial light units appealing. Adjusting the light level and color temperature is one of a limited number of possible environmental manipulations. A recent study (Brown, 2014) funded by Western Michigan University (Kalamazoo, Michigan, USA) FRAACA award was the first 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.

## Methods

Fourteen flight crew members, males (n=9) and females (n=5), working as pilots or flight attendants, participated in the study under the Western Michigan University IRB 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 was provided an informed consent document and attended a two hour training session on the use of the light and actigraphy band. Each participant was provided with a confidential code and completed the Morningness-Eveningness Questionnaire (MEQ), a self-assessment questionnaire (Horne & Ostberg, 1976), 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 19 item, 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). Self-assessed fatigue was recorded using the Samn-Perelli Fatigue Scale (SP), and completed daily psychomotor vigilance tests (PVT). On the third and fourth weeks, the flight crew-members were exposed to blue light (BL) in field-based treatment with short wavelength (460nm) light therapy. Data collection was through the (iOS) Boeing Alertness Model (BAM) application called Jeppesen CrewAlert Lite, which can be used anywhere in the world with an iPhone, iPod, or iPad device.

## Equipment

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 ( $\lambda_{\max} = 465 \text{ nm}$ ,  $84.8 \mu\text{W}/\text{cm}^2$ ,  $39.5 \text{ lux}$ ,  $1.74 \times 10^{14} \text{ photons}/\text{cm}^2/\text{s}$ ) light intervention and is one the smallest light therapy devices on the market, with an advanced optical lens, and a wakeup light alarm. 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.



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 were worn for 30 days by all participants. Actigraphy has been used in studies to measure sleep/wake patterns for over 20 years (AASM, 2010). 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 a day for days, weeks or even longer. The waterproof Motionwatch 8 provide usb downloaded activity plots coupled with specialized software used to quantify the intensity and duration of daily physical activity. These 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. The band also measured the amount of lux the participant was exposed to.

## 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. 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).

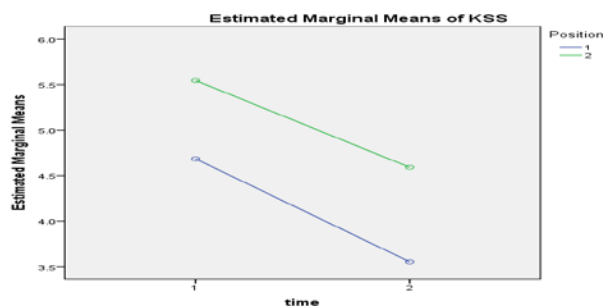


Figure 2. KSS Sleepiness Pre/Post Intervention Marginal Means by Position

Figure 2 above 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). 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 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 (Gillberg et al., 1994). 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.

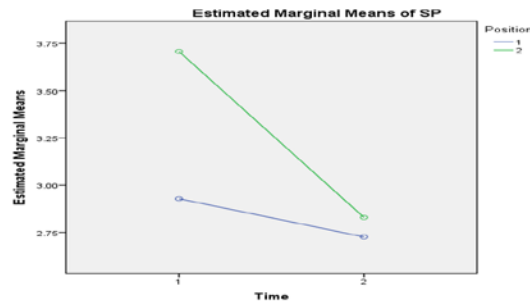


Figure 3. SP Pre/Post Intervention Marginal Means by Position

Figure 3. above shows that for the measure PVTR there is a positive intervention effect (reduced reaction time) for cabin crew, but not for flight crew. However, there is still a difference in the estimated marginal means related to crew position (1 = flight crew and 2 = cabin crew). 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 (Samn and Perelli, 1982). 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.

Figure 4. below shows that for the measure PVTL there is a similar intervention effect for both flight crew and cabin crew, but there is a difference in the estimated marginal means related to crew position (1 = flight crew and 2 = cabin crew).

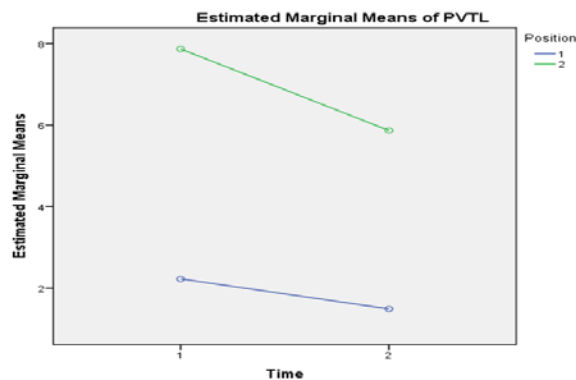


Figure 4. PVTL Pre/Post Intervention Marginal Means by Position

The results reveal that crewmembers may be able to improve behavioral alertness with the use of bright light interventions as a fatigue countermeasure to improve occupational safety in transportation. A review of literature and results of this study shows the acute alerting effect of blue light to be a potentially useful countermeasure to reduce physiological, perceived, and cognitive fatigue, where conditions allow its use. Results garnered can be used to develop innovative light therapies and preventive strategies for industries with shift workers such as aviation, maritime, rail, nuclear, and medical.

### **Recommendations**

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. 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 peak 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.

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. 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. Providing future research looks into the spectral sensitivity of alertness and how it changes over the course of 24 hours, this would be helpful for building light into bio-mathematical alertness models. Light therapy is not new to Western Michigan University (WMU) or the aviation industry. Currently the WMU health center (sindecuse) offers light therapy for students and faculty aimed at the treatment of seasonal affective disorder. Additionally, sky effect lighting has replaced florescent tubes in a WMU classroom to improve concentration for students, along with an innovative 'light bar' was installed in the student lounge area at the College of Aviation. Students can bask under light therapy while studying or relaxing in between classes. The light bar is also used to educate students about the relationship of fatigue and aviation accidents, countermeasures and alertness strategies. This is an opportunity to apply the same concepts to transform countermeasures in the flight deck. Recently, we have seen a flux of light therapy innovations aimed at passengers to improve mood, decrease effects of jet lag and minimize fatigue, include commuter train installations in the UK. Next generation aircraft such as the B787, and A380 have mood lighting installed to help passengers adjust to new time zones. Paris Charles de Gaulle airport installed three light therapy 'spaces' where passengers can enjoy light therapy to fight their jet lag. The light can be used before, during, or after the flight. The Nature Bright Company Sun Touch 'light boxes' are currently used in light bars at WMU, medical facilities, and at airlines such as Novair.

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