Paper

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by Achim LEDER, Dr., jetlite GmbH

How to Reduce Jetlag by Innovative Cabin Lighting

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Abstract

First study: The purpose of this paper is to examine how chronobiologically effective cabin lighting increases comfort and well-being for passengers on long-haul flights. The experience of comfort and positive emotions during a long-haul flight depends on many factors. In addition to seats, cabin climate, vibrations, turbulences and external influences on the flight, light in the aircraft cabin plays another important role. Chronobiologically improved cabin lighting concepts by new LED-luminaires may enhance passenger-comfort on long-haul flights by increasing in-flight relaxation and activation levels at the destination. The conducted experimental study compares conventional cabin lighting with new modified LED-technology. In the context of six simulated long-haul flights (within-subject-design; 21:00 - 07:00 h; n = 32) comfort and emotions are measured by saliva-melatonin, ECG and self-reports. The results show higher comfort and positive valence in the warm white LED condition and the circadian effectiveness of blue light within a daily routine building the foundation for future related studies on behalf of preventive Jetlag-reduction.

Second study: In order to prove the effect of chronobiologically improved cabin lighting in real-life environment, a second study has been carried out together with Lufthansa, the institute of experimental psychophysiology and the Ludwig Maximilian University of Munich. The aim of the study was to analyse the relationship between chronobiologically modified cabin lighting and indicators of well-being and jetlag symptoms on board of long-haul flights. For this purpose, 77 business class passengers were accompanied on various Airbus A350 flights from Boston to Munich. Subjective and objective indicators of emotional, cognitive and sleep-related symptoms were collected during the flight and in a four-day follow-up survey. Based on the extensive research literature and the previously conducted study, it was expected that adapted lighting scenarios could contribute to an improvement of well-being and a reduction of jetlag symptoms. The results of the subjective and objective indicators recorded correspond to the anticipated changes. In summary, the findings obtained here support the initial hypothesis of the effectiveness and acceptance of chronobiologically adapted cabin lighting.

Comfort enhancement by chronobiologically improved cabin lighting

Impact of Light

In addition to its visual effects, light also has non-visual effects on human biology. The visual system allows us to see and focus on objects, and it is most sensitive to green light. The non-visual system, on the other hand, controls bodily functions, detects light from sky, and it is most sensitive to blue light, so that the blue light can be considered as the key regulator to stimulate non-visual effects[1]. The inducement of these non-visual effects has multiple actors. A non-visual receptor called "Intrinsically photosensitive retinal ganglion cells" (ipRGC) found in the mammals' retina records light and darkness phases and forwards the information directly to the supra-chiasmatic nuclei (SCN), instead of the visual cortex[2]. The SCN in the hypothalamus host the master circadian clock that organizes and orchestrates the timing of all daily biological functions, from complicated physiological systems to single cells[3].

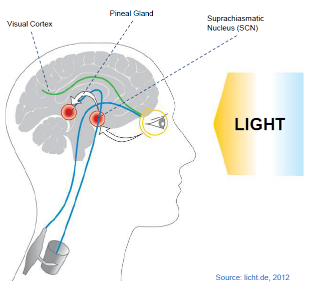

Figure 1: Depiction of the retino-hypothalamic tract

Light for More Relaxed Passengers

Human Centric Lighting (HCL) is lighting that considers both the visual and non-visual effects of exposing humans to light. The following study examines the application of this concept through aircraft cabin lighting, to increase the passenger comfort and well-being.

Considering the theoretical background of HCL, the use of activating lighting systems based on LED could improve recreational and comfort values for passengers on long-haul flights. Warm white light promotes relaxation and well-being, hereby the flight may become more comfortable for passengers and they could rest well. Cold white light with a high proportion of blue color has an activating effect, leading to the suppression of the melatonin (sleep hormone) production [2]. This could allow passengers to reach their destination more relaxed and activated.

Experimental Setting

The twin-aisle aircraft cabin mockup at DIEHL Aerospace facilities in Nuremberg constituted the core of the experiment. It included new generation LED-lighting and 40 long-haul seats. Standard cabin operations, such as pre-flight passenger safety briefings or catering services, were as well executed to create a realistic atmosphere.

The experiment consisted of six 10h simulated night flights in Economy Class, including 32 subjects with an average age of M = 23,44 years. There weren't any diversities in chronotypes (circadian rhythm characters) and the subjects did not have any particular sleep disorders.

In order to allow a comparability, that is not influenced by other boundary conditions, all the simulations were started (Take-off) at 21:00 and finished (Landing) at 07:00 local time. The timing of cabin operations, including catering service, was adapted from the guidelines of similar flights of Lufthansa, Air Berlin and Japan Airlines.

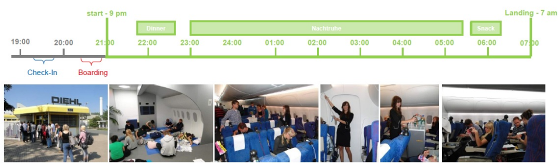

Figure 2: Simulation course and impressions from the experiment day

Light Setting

The developments in LED-technology, especially its advantage in terms of energy efficiency and maintenance, have prompted the aircraft manufacturers to use it in first place for reading lights and then increasingly for general cabin lighting[4]. A further step was taken, in which the lighting was not only being used for visual assistance, but for creating a pleasant ambient, also known as *Mood Lighting*, by creating a colorful cabin atmosphere[5].

In this case, a chronobiological adjustment to cabin lighting demonstrates a step beyond that, by having a psychophysiological effect and ambient lighting at the same time. By this means, the passengers not only enjoy the cozy atmosphere through visual delight, but as well passively undergo physiological process that increase their well-being. In accordance with this background, the light setting was designed and the dynamic sequences were arranged accordingly.

The light setting consisted of two different lighting concepts with distinct illuminance levels, light spectrum and timing. The first one, the reference lighting, is based on the "Airbus Standard Cabin" and the data collected under this setting represents the reference values to be compared [6]. The second one, the interference lighting, is the foundation of this study, based on new chronobiological findings and HCL essentials. Figure 3 illustrates the course of both settings throughout the flight simulation.

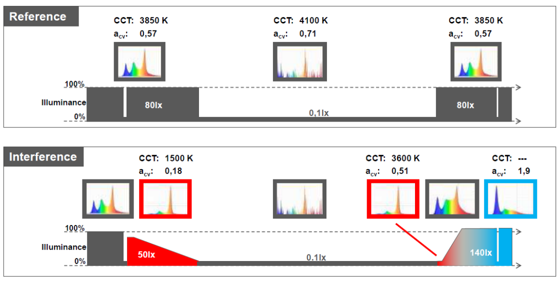

Figure 3: Illuminance and color progression of both settings

Scientific Setting

The experiment had a Within-subject-design. The subjects were divided into two groups and the groups had no contact over the course of whole experiment, which lasted 7 days - starting from arrival of the groups until their departure day. The flight simulation of each group was conducted one at a time, so that each night one group was "flying" in the mockup and the other group was recovering in the hotel. Each group had three flights, consisting of one with reference cabin lighting and two with interference.

Within the scope of instrumentation, various indicators of comfort were logged. For this purpose, the subjects filled out questionnaires, which provided data regarding their well-being, fatigue, emotional state and stress levels. Additionally, the heart-rate variability was monitored as a cardiovascular parameter for stress. Cortisol and melatonin levels, stress and sleep hormones, were monitored through saliva-examination. The observer rating and head-motion-tracking could be analyzed by video recording. Motion- and acceleration sensors on subjects' bodies collected data for motion-tracking.

Results

Both self-reports and saliva-examinations show that the chronobiologically modified cabin lighting does have a positive impact on the passenger comfort, in which the results demonstrate a relaxation of the passengers during the initial phase of the flight simulation and a clear activation towards the end of the simulation.

When comparing the results from both light settings, the surveys on stress levels show quite similar progression in the first flight phase, although the chronobiologically modified one having lower values in total. In the flight phases after the sleep phase, there is more difference to be observed, meaning the subject passengers felt themselves less stressed under such lighting, than the standard one.

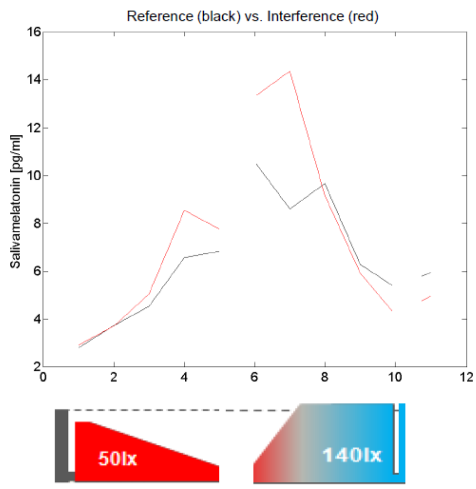

Figure 4: Melatonin levels from the salivia samples. The black line represents the reference setting and red line the modified setting

The next step to validate the results was to implement this concept into a real flight, in which the jetlag phenomenon clearly occurs. This validation demand could be realized with Lufthansa through series of tests on a flight, that covers multiple time zones in relative short time (6 time zones in 7 hours 20 minutes).

Test Flights Conducted with Lufthansa

To analyze the correlation between the chronobiologically improved cabin lighting and passengers' well-being and jetlag symptoms on long-haul flights, a series of test flights were conducted in cooperation with Lufthansa and Ludwig Maximilian University of Munich. For this purpose, 77 Business Class passengers were monitored and followed up on some of Lufthansa's Boston-Munich flights with Airbus A350, starting from the Business Lounge of Boston Logan International Airport until the fifth night after their arrival in Munich. The subjective and objective indicators of emotional, cognitive and sleep-related symptoms could be surveyed throughout the flight and the follow up phase. The ascertained results and findings of this scientific examination collectively indicate the effectiveness and acceptance of the above mentioned hypothesis regarding the chronobiological impact of the aircraft cabin lighting.

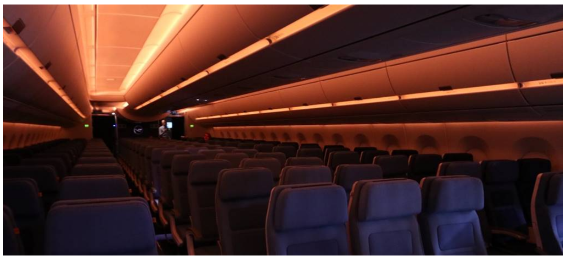

Figure 5: Lufthansa Economy Class of a Airbus A350 with improved cabin lighting

Analysis methods

By means of random sampling, a total of 77 passengers were monitored, with an average age of M = 48,0 years (SD = 11,6). The majority (69%) of the passengers were frequent flyers up to test time, flying a yearly minimum of 6 long-haul flights (>6h).

The experimental protocol consisted of 13 questionnaires to be filled out by passengers: prior and during boarding (2), after take-off (3), prior to landing (3), in the evening of arrival (1) and in the following four nights (4).

Instrumentation

As part of the instrumentation, various scales and grading methods were implemented into the test scope, which are internationally adopted by medical research institutes focusing on the topic of jetlag. These studies provide a scientific baseline and also enable to quantify the questionnaires' outcome. They include the Munich ChronoType Questionnaire (MCTQ) [7], the Positive and Negative Affect Schedule (PANAS) [8], Charité Jetlag Scale [9] and Jetlag Recovery Score [11]. The surveyed results were investigated under three points: Well-being indicators, sleep activity and jetlag symptomology.

Well-being

The subjective emotional well-being of the passengers were evaluated via PANAS and the effective drowsiness via Karolinska Sleepiness Scale (KSS) [10]. Following a scale conversion, a scale of 1-10 was adopted, value 1 representing the minimum comfort and 10 the maximum.

Sleep Activity

Items regarding the sleep behavior were surveyed - covering a span of four weeks' time. As well as the chronotype specific data was collected through MCTQ. A large number of passengers were resting and couldn't make any remarks during some of the survey times, which is evaluated as a positive result for sleep phase of the flight, pertaining to the "deactivating" impact of cabin lighting.

Jetlag Symptomology

The evaluation of the jetlag questionnaire was carried out in accordance with Charité Jetlag Scale, by deducing a weighted total score from 18 symptoms of 4 different symptom groups (cognitive, physical, vegetative and sleep related). To quantify the recovery rate of jetlag symptoms, a Jetlag Recovery Score was taken as basis. The evaluation of this scoring was then compared with the reference values of a further study (Becker et al., 2016) [11].

Results

The results of the flight test exceed the expected values. The overall sense of comfort during the flight was increased through the improved cabin lighting. The average value of subjective comfort M = 8,29 is 5,5% greater than the estimation based on empirical knowledge (M = 7,84). Further data showed that the passengers appraised the quality and comfort characteristics of the lighting. In particular, high values were obtained regarding light color, light quality and light aesthetic.

Within the individual scales, diverse expressions of emotional states, such as active, alert, attentive, support the chronobiological influence of the lighting. The activeness, alertness and attentiveness decrease in the evening prior to sleep (Lighting scenario *Dinner* and *Sleeping*) and increase in the morning prior to landing (Lighting scenario *Wake Up*), as shown in Figure 6. Such perception feedback complies with the expected impact of the lighting scenarios: sleep induction by reducing the blue proportion of the light in the evening and activation by increasing the blue proportion in the morning.

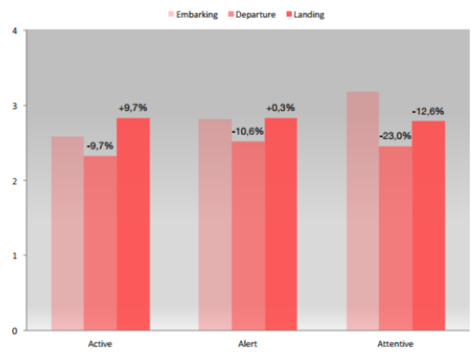

Figure 6: Surveyed levels of emotional states in different flight phases

Moreover, the sleep expectations of the passengers were clearly met, so that the ones expecting to sleep could get a rest during the sleep phase and 88% of those ones that had not expected to sleep depending on their previous experiences, were able to sleep. Correspondingly, the sleep quality had an increase of 7% as compared to predicted reference value.

Despite having a greater time shift than the reference study [11], the jetlag prevalence of the passengers has 11% less percentage points than this study. The same statement applies for the comparison by means of Jetlag Recovery Score. Figure 7 points out this difference between the vulnerable passengers' score and the reference score over the course of post landing phase.

Additionally, passengers compared the new lighting concept with the conventional ones. The color transitions and gradients were positively evaluated, which indicates a small but significant impact of the new lighting concept on visual-system of the observers.

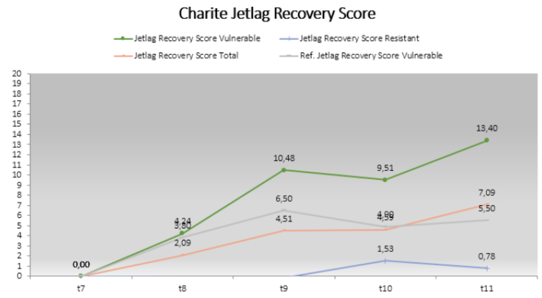

Figure 7: Comparision with Charité Jetlag Recovery Score with reference values [11]

Conclusion

It is becoming clearer that human health and well-being are dependent upon the synchronization of biological systems [12]. Furthermore, a great deal of research and development has been undertaken to accurately reveal the benefits of Human Centric Lighting, in order to use light as an effective instrument for influencing the overall well-being of humans [13]. Both studies show that by applying the fundamentals of HCL, the aircraft cabin lighting can be used to increase passenger comfort and mitigate jetlag symptoms. The first study (Leder et al. 2013) examines these effects on a scientific basis and in practice - in a wide body aircraft cabin mockup. The second study, application on test flights, proves the hypothesis of the first study in real environment - in a wide body aircraft Airbus A350 flying from Boston to Munich. As a result, one can conclude that the chronobiologically improved cabin lighting provides an enhancement of passenger well-being and can also be used on behalf of preventive Jetlag reduction.

Author's CV

Achim LEDER, Dr.

Achim Leder is founder and CEO of jetlite. Leder studied Economics & Management at Free University of Bolzano. After his graduation he completed his studies with a Master in Business & Engineering at Steinbeis University Berlin. Since then Leder worked in the aviation sector in different positions at EADS/Eurojet and Dortmund Airport. From 2011-2014 Leder studied for his PhD the effects of cabin lighting on passengers. Based on his PhD-Thesis and diverse surveys from all over the world, Leder defined the jetlite-algorithm that regulates the light on board in respect to different flight parameters to reduce the effects of jetlag.

Organisation

jetlite

More than 60% of all passengers on long haul flights suffer from jetlag. This is not only a problem for passengers themselves but also causes billions of dollars losses for economy. Besides, airlines aim for differentiation and perfectly satisfied guests. jetlite's mission is to reduce jetlag, increase passenger-comfort and satisfy airlines & aerospace needs regarding the needed knowledge of the real impact of lighting and food over the whole passenger journey. jetlite offers a holistic algorithm-based approach to increase the comfort of passengers (pre-, in-, and post-flight) by reducing jetlag on long-distance flights. jetlite mainly focusses on (1) chronobiologically improved lighting for aircraft, airports and even personalized for passengers before and after the flight, (2) customized nutrition concepts for airline-catering and airport-services, as well as (3) personalized suggestions for passengers via an app regarding sleep-, light- and nutrition-impact, which together form the backbone of this scientifically proven solution. jetlite can increase the comfort and satisfaction of passengers while reducing fuel consumption and the workload for the crew on board.

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