IMPACT OF WORKPLACE ENVIRONMENT ON HEALTH AND COMFORT OF FLIGHT ATTENDANTS AND PILOTS - RESULTS FROM THE EU PROJECT HEACE

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Abstract

The workplace, well-being, comfort and health-issues of cabin and flight crew were investigated in the EU-Project HEACE in simulated and real flights. The environmental conditions have significant impact on various symptoms and health indices. The relation between environment and subjective response is complicated in real flights and not fully understood, whereas simulator experiments reveal clear relations between physical and subjective and medical parameters.

The prognosis of the human response to the environmental condition is well possible with an appropriate artificial neural network. The statistical analysis of identifiable input-output relations is not yet completed. This analysis will support an optimization of relevant design parameters of the work place environment in cabin and cockpit.

1 Introduction

The investigation of health effects in aircraft cabin environment was the objective of the EU project HEACE (www.heace.org). The aim of the research was to develop a model which relates the environmental impact at the workplace of flight and cabin crew to health parameters, to subjective comfort, to performance, in order to derive recommendations for an improved design of the interior of cabin and cockpit. The project collaborated with the EU technology platform FACE, in which passengers were investigated with a similar objective (passenger comfort index).

HEACE was carried out together with partners from Building Research Establishment (BRE), Medical University Vienna, EADS-CRC, CIRA, University of Patras (LFME), itap GmbH and Paragon Ltd. A huge amount of data was obtained, and the analysis is still running.

2 Test design

Variation of environmental conditions in real flight is limited, and experimental set-ups have to meet strong boundary conditions by taking safety issues into account. It is therefore useful to conduct experiments in a simulator facility which provides a sufficient virtual reality. The question is still unsolved how “real” a simulation has to be in order to allow transfer of results to the real flight situation. Experiments were carried out in HEACE in both simulators and real flights. The environment in real flights cannot (really) be changed by purpose, but monitored. The environment in the simulator is in general adjustable according to the specific experimental design.

Simulator tests were carried out in the emergency trainer of Austrian in Vienna and in the ACE test facility of BRE in Watford [4]. The design comprised a long questionnaire to be used before, during and after the test period, a full three-step variation of the three environmental parameters sound (and vibration), humidity, temperature, and extensive monitoring of these parameters. Additionally, numerous physiological and health indices were registered. 22 pilots and 86 flight attendants serving 544 (simulated) passengers participated in the simulator tests. The experiments were complimented by 6 real long-haul flights, in which altogether 132 flight attendants and 30 pilots participated.

2.1 Questionnaire design

Questionnaires were designed based on extensive experience in psychophysical research for car industry and the EU project IDEA PACI [1] as well as the knowledge gained from the EU project CabinAir [2]. The questions based on interviews with the respective personnel and on extraction of appropriate adjectives describing the cabin and cockpit environment. In the next step, semantic differentials were derived and tested with experts. The design of appropriate scales (in general a 7-point scale as fixed by other guidelines (e.g. [3])) was formatted for electronically reading, and finally an estimation of time to fill-in the questionnaire gave the frame for the experimental procedure in simulators and real flights. The scale could either be bipolar (e.g. -3 to + 3), or sometimes unipolar (e.g. 1 – 7 or 1 – 5).

Fig. 1 gives an example for questions related to “noise in the cabin”.

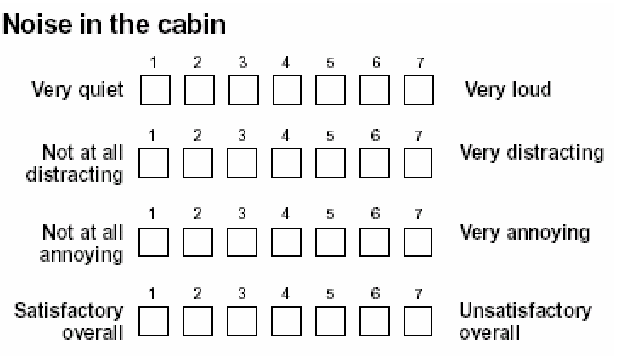

Fig. 1. Example from the questionnaire (unipolar scale, electronically readable)

Fig. 2 gives an impression of the distribution of questionnaires to passengers in the ACE simulator [4]. The crew member is wired so that physiological parameters are monitored.

Questions addressed some 120 items from following areas

- health and well-being (30 items)
- environmental conditions (45 items)
- control over environment (8 items)
- relative comfort contribution (18 items)
- effect of the environment (18 items)
- ability to work (8 items)
- alertness and mood (9 items).

Fig. 2. Distribution of questionnaires in the ACE simulator. The FA carries a mobile data logger to monitor physiological parameters.

The questionnaires were designed by the partners from Oldenburg University, Medical University Vienna and BRE.

The questionnaire for the passengers (FACE project) was similar, except for work-related items and with additional comfort-related items.

2.2 Flight tests

Measurements were made during six long-haul flights with the support of Austrian Airlines: Vienna-Delhi-Vienna (8 h duration) and Vienna-Tokyo-Vienna (12 h duration) in A330 and A340.

Data were measured in cockpit, galleys, cabin, and crew-rest compartments at various locations. The experiments were carried out with the help of Oldenburg University, Medical University Vienna, EADS-CRC, itap GmbH and Paragon Ltd.

Following environmental parameters were measured:

- sound and vibration (time history and level)
- temperature
- humidity
- draft
- air quality (CO2, CO, VOCs, number of germs)

In parallel and practically coherent in time the physiological parameters

- heart rate and -variability
- blood pressure
- oxygen saturation
- salivary cortisol
- skin conductance

were monitored while questionnaires were filled in by the crew members after service (3 times during Tokyo flight and 2 times during Delhi flight).

economy compartment in the middle of the fuselage near the wings). Both planes have about the same noise level in cabin and cockpit during the flight tests except for the aft of the A330, where the level is slightly increased (due to the louder engines). The analysis of the human response has to take into account all environmental data, e.g. level and spectral distribution of interior noise as well, which might possibly affect a symptom or medical index.

2.3 Simulator tests

Pre-tests were carried out in the emergency trainer of Austrian Airlines in Vienna (see Fig. 4). This simulator has the advantage to give quite good virtual reality with respect to noise, vibration and motion but lacks of stable conditions for temperature and humidity. Final simulator tests were carried out in the ACE at Watford, which allows for an excellent stabilization of climatic conditions (except pressure), even at very low humidity [5], but has the disadvantage not to provide motion which lowers the impression of virtual reality (interior of the ACE, see Fig. 2).

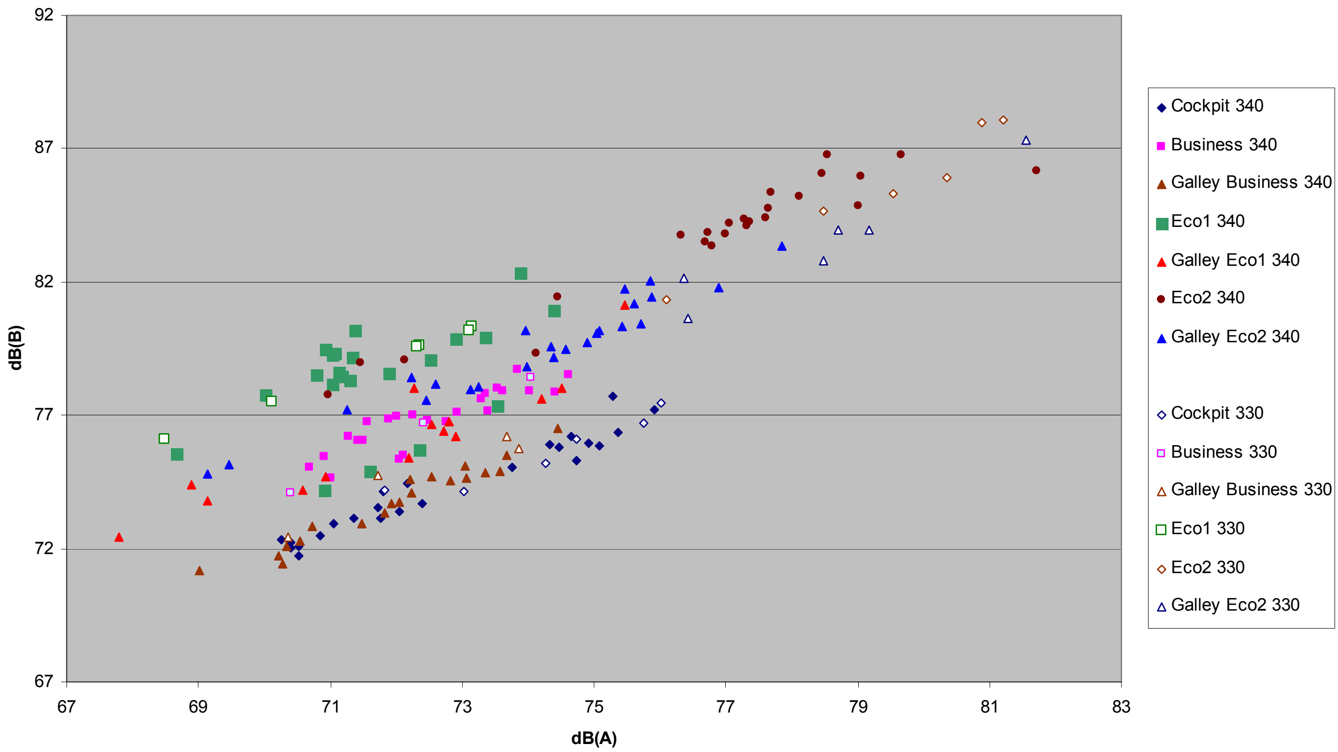

Fig. 3: Distribution of A- vs. B-weighted sound level in cockpit and cabin for A340 (filled symbols) and A330 (open symbols) during questionnaire periods.

An example for the environmental condition related to sound pressure level shows Fig. 3. A difference between A- and B-weighted level indicates additional low-frequency contributions (most pronounced in the first

The simulator experiments were carried out by BRE, Medical University Vienna, itap GmbH and Oldenburg University.

Due to limitations of the facility simulator flights could only take place with a duration of 3 to 4 hours daily. A full 3 × 3 × 3 factorial test design was chosen: 3 levels of noise (and vibration, which was derived from the sound signal), 3 levels of temperature and 3 levels of humidity. The lowest noise level was determined by the background noise of the air conditioning. Because the whole set-up (including test persons) has a considerable relaxation time with respect to the target levels for climate (in particular for the humidity), the test design was chosen such that during a simulated 3-hour-flight temperature and humidity were kept constant and noise was adjusted to the given three levels (with a smooth transition which was not noticeable, not even for the supervisors of the experiment). Table 1 gives the test matrix.

temperature [°C]	21 - 22	24 - 25	27 - 28
relative humidity [%]	5 - 10	15 – 20	25 - 30
sound level [dB(A)]	70	73	76

Tab. 1: Test design in simulator with parameter ranges as observed in the fuselage. The target values for sound were not met in the cabin at each place, the levels range about 70-76, 73-78.5, 75-80.5 dB(A)

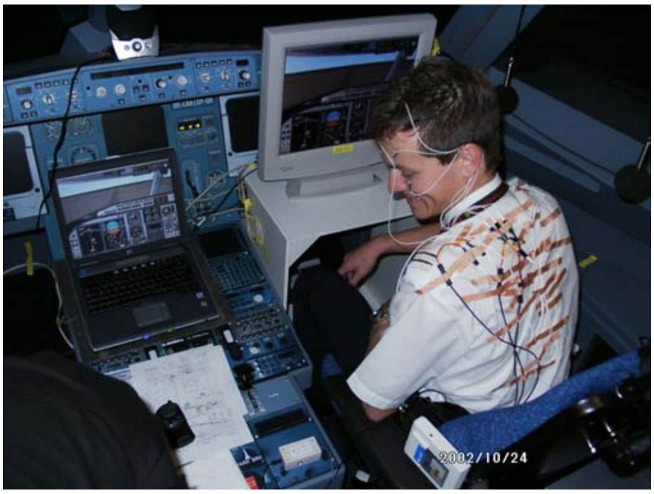

Fig. 4. “Wired” pilot during pre-test in the simulator of Austrian Airlines

In summary, a simulator flight started with boarding, welcome address, “start” procedure, one hour “flight” at a given noise level, catering, one hour “flight” at next noise level, catering, one hour “flight” at third noise level, landing procedure.

The climatic conditions were kept constant during this session. Questionnaires were filled in after each service by the crew.

3. Data analysis

All tests provide input to a huge data matrix: Each row contains one questionnaire related to one person in a certain period of activation with corresponding environmental data, medical data and log-data of the respective flight situation. The data analysis is still ongoing.

The physical (environmental) data are measured and analysed according to the technical state-of-the-art, e.g. loudness in Sone, speech interference level SIL, PMV of local thermal comfort, CO and CO_2 with commercial sensors, VOCs with probe tubes and following mass-spectroscopy (according to procedures defined in [11].

The medical (physiological) data of each crew member and test person are analysed by the Medical University Vienna and summarized in representative (vector) indices [6, 7, 8] characterizing

- “load” indices for physiological state and physiological reaction to external stressors
- “imbalance” of subject’s physiological status
- alertness, energy, and mood
- subjective health
- performance

Theses indices are not further discussed in the present paper.

Two major approaches are employed in order to relate the environmental condition (including certain intrinsic parameters of each test subject) to the subjective and physiological response of the crew:

- Artificial Neural Network (ANN)
- Statistical Approach (SA)

The ANN [9, 10] uses an input vector of (partly pre-processed) environmental data and calculates with several intermediate layers an output vector, which is representative for one of the indices mentioned above. The ANN-model works with an error below about ½ step-size of the subjective scales. The ANN approach is not further discussed in the present paper.

The SA uses tools (like analysis of variance ANOVA, principal component analysis PCA, correlation analysis) to identify relevant environmental and intrinsic parameters which contribute to a certain output of a crew member, e.g. a medical or psychological index or symptom. At a first step it was analysed, which dependant parameters and data exhibit sufficient variation in answer to the given independent range of environmental conditions. This causes a reduction of all measured questionnaire data of about 65%. In the next step, a PCA revealed the space of perception of all subjective data, indicates those items which cluster, and gives an estimate which perceptions are correlated with independent variables, e.g. an environmental condition. An ANOVA revealed direct and indirect relations between selected items from the independent and dependant variables. In the following selected results from the questionnaires with respect to noise and vibration are discussed.

3.1. Data from flight tests

A PCA of all data from the questionnaire (i.e. data from all tested crew members, who were at work during flight) reveals clear clusters of similar *perception*, which can be arranged in 11 dimensions related to

- noise-effects (like distraction, annoyance due to noise, etc.)
- symptoms (like headache, dizziness, etc.)
- vibration effects and motion
- perception of temperature, local climate
- motivation, concentration
- perception of air quality
- request to change of certain condition
- communication (incl. intelligibility)
- perceived draft and overall comfort
- symptoms related to dry air
- symptoms related to muscle/ joint pain

Fig. 5 gives two impressions of the space of perception: The plane of dimensions 1 and 3 and the plane of dimensions 2 and 4.

Obviously (Fig. 5a), the factor 1 relates to noise-effects and the factor 3 to vibration/ motion (with a little component of “noise-perception”).

Fig. 5b indicates that numerous symptoms cluster around a factor 2, and perceptions related to climate form factor 4.

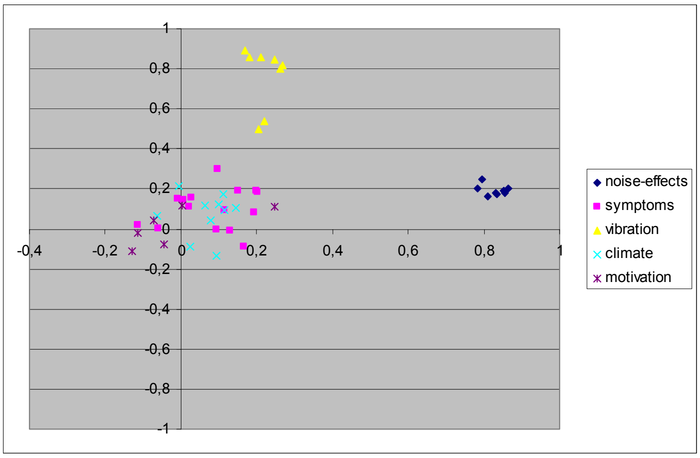

Fig. 5a. Plane [Factor 1 – Factor 3] of a 11-dimensional space of perception.

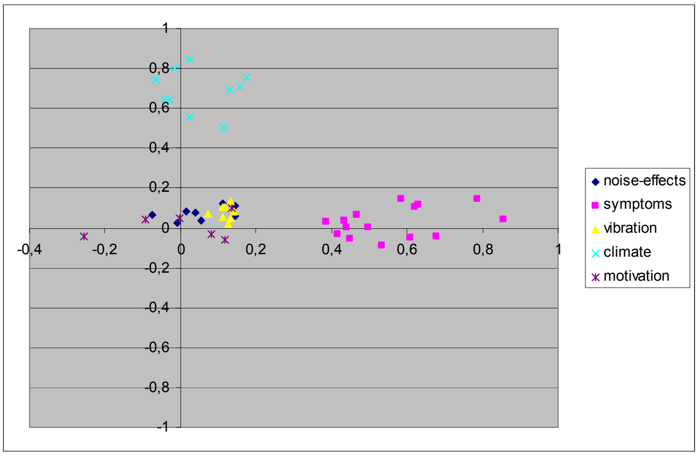

Fig. 5b. Plane [Factor 2 – Factor 4] of a 11-dimensional space of perception.

The correlation of physical environmental parameters like noise level (Fig. 3) exhibits only a small (but still significant) link to the subjective perception. A simple linear correlation is not appropriate to take the changing environmental condition, the mutual interaction, and the complex task load of the crew into account in order to reveal clear relations between independent and dependant variables. It becomes therefore necessary to identify significant parameters with the help of ANOVA.

Fig. 6 gives the subjective development of the air quality (scale from “fresh” to “stuffy”) in the cabin throughout the whole flight from the beginning (phase 1) to the end (phase 3) for all long-haul flights Vienna-Tokyo-Vienna. The dependency of the perception is highly significant (error < 1%) and shows a degradation of the perceived air quality of about 15% (i.e. 1 step of the 7-step scale).

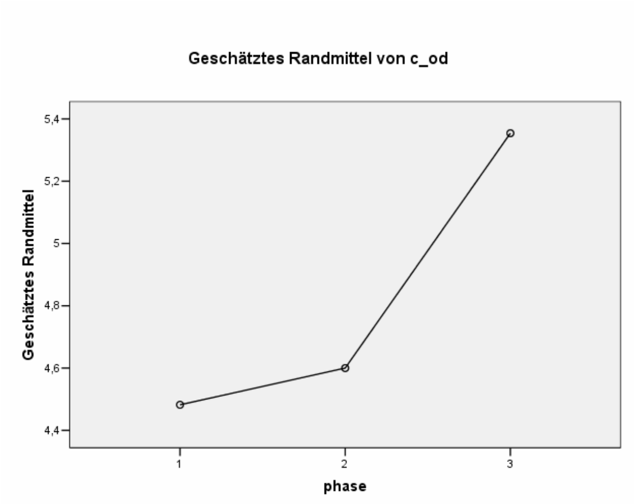

Fig. 6. ANOVA of perceived air quality shows a significant change from “fresh” to “stuffy” with flight duration.

The observation does not necessarily indicate an objective change of air quality. Measurements of independent air quality parameters do not exhibit any degradation. But Fig. 6 points towards an increase of sensitivity of the perception of environmental conditions, which is confirmed by Fig. 7.

Fig. 7 shows the analysis of a typical symptom (“do you have swollen legs/ feet?”) during the three flight phases under the condition of varying noise levels. The perception of this symptom increases significantly with the noise level in the cabin, in particular at the end of the flight (phase 3) the swollen feet become aware with an increase of 43% under noisy conditions compared to quiet conditions in the beginning (phase 1). The result is highly significant with an error < 0.3%.

Another symptom, which has obviously direct impact on the ability to work, is muscle pain in the neck. Fig. 8 shows a pronounced increase of reported pain with increasing noise level.

The symptom is nearly independent from the flight phase, but increases 57% (error < 0.4%) with the noise level. (the step from “1” to “4” is equivalent to about 8 dB(A)).

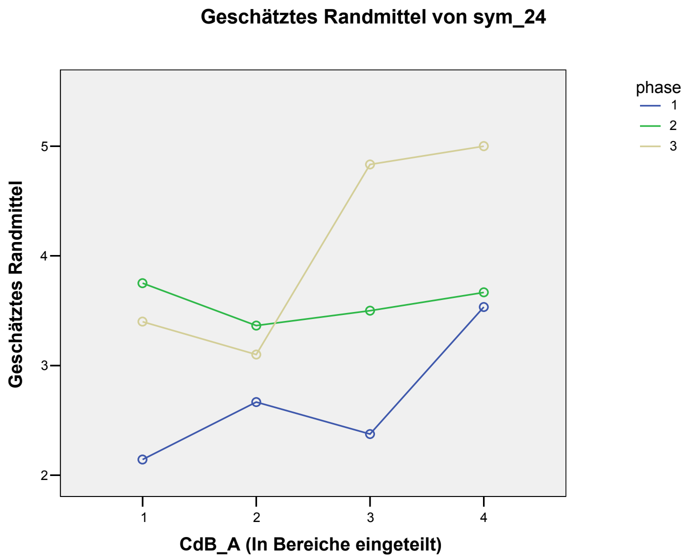

Fig. 7. ANOVA of symptom “swollen feet” during beginning of flight (phase 1, blue line), in the middle (phase 2, green line) and the end of the long-haul flight (phase 3, grey line), dependant on the noise level dB(A).

All results in Fig. 6 to 8 do not take into account the direction of the flight, i.e. if the flight is going from “home” to the remote destination or back “home”. Some symptoms like the subjective ability to concentrate (also supported by psychological tests), show a pronounced influence of the flight direction. ANOVA gives a degradation of “concentration” of about 14%, averaged for all flights, when travelling “home” (error < 0.1%!).

Insight into the complex interaction of the different parameters is gained with the help of simulator experiments, which provide investigations under defined conditions with a reduced selection of variables.

3.2 Data from simulator tests

The experimental set-up (Table 1) allows for the study of variation of two main conditions: Noise and climate. With 22 flight crew and 86 cabin crew members serving 544 passengers a PCA exhibits a two-dimensional space of perception, as expected from the test design. One factor relates to all items related to "noise". This result is in agreement with the observation of the flight tests. Additionally, the dB-level relates well to this subjective factor.

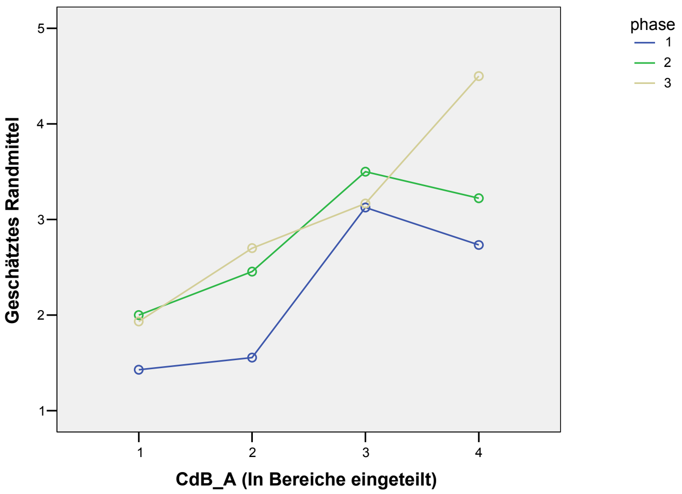

Fig. 8. ANOVA of symptom "muscle pain in the neck" during beginning of flight (phase 1, blue line), in the middle (phase 2, green line) and the end of the long-haul flight (phase 3, grey line), dependant on the noise level dB(A).

The second factor includes all items related to the air quality and views related to temperature conditions.

The test design (Table 1) was such that during Case I of the simulated flight the noise level increased (step 1, 2, 3) and during Case II the level decreased (step 3, 2, 1) monotonously. ANOVA showed following dependencies

Case I: The noise level has significant impact on (error in brackets)

- level of distraction (3 %)
- level of annoyance (1 %)
- overall satisfaction (< 1 %)
- perception of vibration (< 2 %) and movement (< 1 %)
- symptoms (< 1%)
    - o lethargy/ tiredness
    - o difficulty in concentration/ remembering
    - o swollen or heavy legs/ feet
    - o headache

Case II: The noise level has no significant impact on any of the previous items except for the "perceived volume of noise in the cabin".

An obvious interpretation of this observation is that symptoms in general increase with time, but awareness is lowered if the noise level is decreased. If the noise level increases, the crew members become aware of the change of symptoms (Fig. 9).

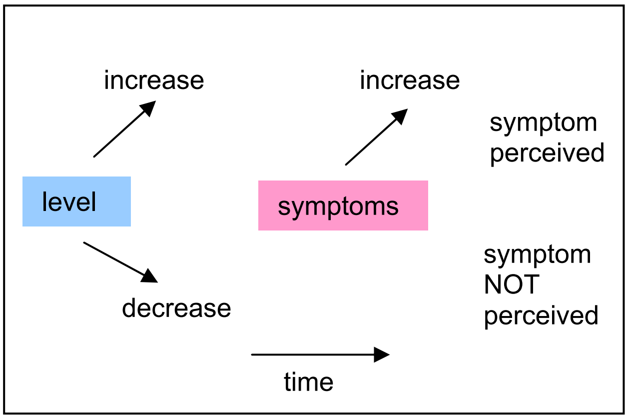

Fig. 9. Scheme to illustrate the trade-off between reported symptoms and change of noise level.

4. Summary

The HEACE project investigated the impact of the environmental condition at the workplace of cabin- and flight crew on the well-being and performance and health of the crew. Measurements in long-haul flights and tests in flight simulators were conducted. Various indices were developed to characterize the human response. A relationship between independent variables (the environment) and dependant variables (the human response) is well described by an ANN. Direct input-output dependencies of selected parameters reveal a complicated mutual interaction of numerous variables. The present paper focus on the impact of the noise level – other parameters are still under investigation. The noise level exerts significant influence on various symptoms and health indices, but the functional relationship depends on various independent parameters as well.

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