



# Ambient Lighting Assistance for an Ageing Population

Specific Targeted Research Project

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## Deliverable 1.2:

### Description of psycho-physiological lighting effects and target values for older adults

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## Preface

This document forms part of the Specific Targeted Research Project (STREP) “Ambient Lighting Assistance for an Ageing Population” (ALADIN) funded by the Information Society Technologies (IST) priority of the Sixth Framework Programme of the European Commission as project number IST-045148. The ALADIN project aims at the following Deliverables:

- D1.1 Specification of the criteria for selecting the test persons, i.e. the sample of users to be involved (incl. a justification for the selection of the sample) and the description of tests to be performed.
- D1.2 Description of every-day events and activities where daylight and artificial light play a major role including the corresponding psycho-physiological effects on individuals.
- D1.3 Description of support and advice measures aimed at preserving the mental and physical fitness of older adults.
- D1.4 Project presentation.
- D1.5 Final plan for using and disseminating knowledge.
- D2.1 Measuring instruments that capture the psycho-physiological data in every-day events and activities of older adults in place.
- D2.2 Modular components that can be combined for achieving cost-effective lighting systems and allow continuous and hardly noticeable changes of certain lighting parameters.
- D3.1 The intelligent and adaptive lighting control system is ready for testing.
- D3.2 GUI with manual user controls for light parameters is ready for testing.
- D3.3 A classical biofeedback solution is ready for testing.
- D3.4 An advice and support application for enhancing the mental and physical fitness of older adults is ready for testing.
- D3.5 Application for visualising one’s psycho-physiological data including information about how these are correlated with one’s emotional and physical state is ready for testing.
- D4.1 Report on the test results and the evaluation of the system as a whole.
- D4.2 Fully functional solution (soft- and hardware) including possible redesigns and extensions.
- D4.3 Description of a general model about the correlations between environmental variables and the psycho-physiological states of older adults.
- D5.1 List of publications, press releases, scientific papers and guidance notes for designers.
- D6.1 Consortium agreement, progress reports, final report including the evaluation results.

The ALADIN project and its objectives are documented at the project website [www.ambient-lighting.eu](http://www.ambient-lighting.eu). More information on ALADIN and its results can also be obtained from:

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# 1 Introduction

According to the Description of Work Deliverable 1.2 comprises the “Description of every-day events and activities where daylight and artificial light play a major role” as well as the corresponding psycho-physiological effects on individuals associated with Task 2 of WP1 (Psycho-physiological effects). However, the description of every-day events and activities has been included in Deliverable 1.1 “Specification of the criteria for selecting the test persons” as this document summarises the results of the empirical research conducted by Apollis, our Italian partner. It describes typical every-day activities of elderly people aged 65+ in private single households in order to model one-room/one-person use scenarios for the ALADIN prototype or future assistance systems. Besides, Deliverable 1.1 provided a survey of user requirements concerning the different components of the ALADIN system like lighting devices, user interface, and body sensors.

Consequently, Deliverable 1.2 is dedicated to the results of the lab tests performed at the Budapest University of Technology and Economics - Department of Ergonomics and Psychology (BME) and Bartenbach Light Laboratory (BLL).

Given the vast amount of data produced by the tests, the results and conclusions in this document are to be regarded as preliminary since the detailed processing and analysis of the data is still in progress. Besides, the researchers from the two organisations have arranged to meet mid-October to discuss the results in detail and agree on a joint set of recommendations for the adaptive lighting system. The final conclusions will be ready by the end of October in time for the next general meeting in Bucharest on Nov. 5-8.

All the data including additional tables and diagrams required to substantiate the findings in the following sections will be available on our project platform ([www.ambient-lighting.eu/confluence](http://www.ambient-lighting.eu/confluence)) by mid-October. The precise location will be communicated to the project officer.

Del. 1.2 also includes preliminary results of the user tests and expert reviews carried out to ensure user-friendly and accessible graphical user interfaces.

## 2 Summary of preliminary results

### Psycho-physiological lighting effects

**Overall, the different lighting situations did have an impact on older adults both in terms of activation and relaxation.** The effects of lighting could be shown in:

- the test persons’ subjective assessments as reflected in the questionnaires
- the performance tests which measured the test persons’ ability to concentrate, and
- the heart rate variability analyses

Bright light produced the most significant effects in the performance tests.

The relaxing effects of all the dim light situations could be shown in the heart rate variability (HRV) analyses, especially in the very low, high and middle heart rate frequencies.

Based on these results we can conclude that bright light of at least 500 cd/m<sup>2</sup> and 6500 K is needed to achieve activation in older test persons.

In practical terms this means that the lighting system should aim at providing a colour temperature between 3000 and 8000 K and a brightness level of max. 750 cd/m<sup>2</sup>.

The adaptive lighting system has to be dimmable in the range from 0 to 750 cd/m<sup>2</sup>. As far as the lighting devices are concerned, these have to offer a colour temperature between 3000 K and 8000 K.

### **Psycho-physiological target values**

**Skin conductance response (SCR) has turned out to be the most appropriate psycho-physiological target value** for the envisaged automatic lighting adaptation, i.e. the intelligent control loop. This parameter proved to be the most sensitive for different activities. For skin conductance response, a very clear and practically important relationship with activation and relaxation levels was found. Besides, this relationship does not only have statistical significance but shows very high absolute differences in pair-wise comparisons. As a further useful benefit, skin conductance response shows no habituation effect.

**Heart rate is the second candidate** as an appropriate psycho-physiological target value. Heart rate significantly corresponds with the high activating and relaxing situations. The absolute differences, however, are very small. All the other psycho-physiological parameters have not proved to be sensitive and/or specific enough due to very high individual differences. They might be used as psycho-physiological target values on an individual level.

### **Preliminary conclusions**

Based on the results we intend to use skin conductance response (SCR) in a similar way as in the study „Evolutionary feature detection in interactive biofeedback interfaces“ performed by Kempter et al. (2005)<sup>1</sup> for fitness evaluation within the genetic algorithm. On the one hand the chosen SCR parameter takes into account the stimulus–reactions relationships within different situations ignoring the long-time effects in skin conductance level. On the other hand it also complies with the general psychological concept of arousal. Skin conductance response can be seen as a reaction to completion and individual appraisal of subtasks. In the best case, stimuli initiated by certain lighting conditions result in increased activation, which in turn leads to a shortened arousal boost, reduced recovery time as well as to a higher arousal amplitude.

On the basis of the light experiments we recommend the use of movement, heart rate and skin conductance. We also suggest supplementing the physiological measurements with

- The use of a questionnaire to gain insight into the subjective sense of wellbeing of test persons, and
- A performance test to measure the degree of mental activation of test persons.

Based on previous experience with physiological measurements in real-life settings it can be stated that it is necessary to calibrate, i.e. capture the current physiological state of the test person before starting the adaptive lighting system. This is in line with the results of other research published on physiology.<sup>2</sup> Besides it is necessary to record, transmit and analyse at least two physiological parameters that are independent of each other.

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<sup>1</sup> Kempter, G., Ritter, W. & Dontschewa, M. (2005). Evolutionary Feature Detection in Interactive Biofeedback Interfaces. Paper presentation at 11th International Conference on Human-Computer Interaction, 22. – 27. July in Las Vegas.

<sup>2</sup> For example, the following publications:

a) Boucsein, W., Haarmann, A., & Schaefer, F. (2007). Combining skin conductance and heart rate variability for adaptive automation during simulated IFR flight. In D. Harris (Ed.), *Engineering Psychology and Cognitive Ergonomics* (pp. 639-647). Berlin: Springer.

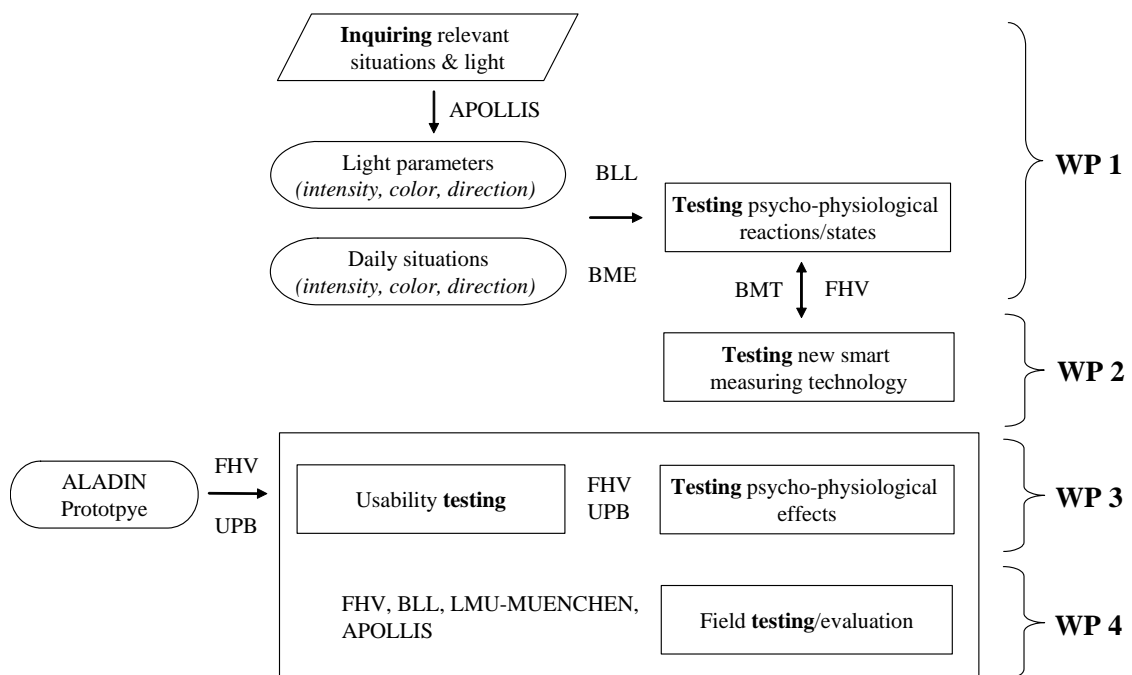
## 3 Experiments and data collection

### 3.1 General background

Deliverable 1.2 is based on the following achievements related to WP1 “User requirements specification”

- Criteria for selecting users for the evaluation phase have been defined. These include a person's health and personal habits (e.g. the taking of certain medicines, consumption of alcohol, coffee and/or other stimulants) as well as motivation for participating in the field test (LMU and BME).
- Several well-defined single person/single room situations that occur in the daily lives of older people have been identified (APOLLIS). Watching TV has proved the most wide-spread activity (see D1.1)
- The requirements and expectations of older adults concerning the role of lighting for every-day activities have been investigated and analysed (see D1.1):
- The test designs and test procedures for defining the psycho-physiological target values for all selected situations have been drawn up (BME; see D1.1).
- The test designs and test procedures for defining the psycho-physiological effects of various lighting parameters (e.g. lighting intensity, colour, distribution, flicker) for each of the selected situations have been drawn up (BLL; see D1.1).

The figure below illustrates the different steps of testing and how they are interlinked:



**Figure 1: Different steps of empirical testing**

b) Villon O. and Lisetti C. (2006): A User-Modeling Approach to Build User's Psycho-Physiological Maps of Emotions using Bio-Sensors. In proceedings of IEEE RO-MAN 2006, The 15th IEEE International Symposium on Robot and Human Interactive Communication, Session Emotional Cues in Human-Robot Interaction, Hatfield, United Kingdom, September 8, 2006, pp 269-276.

### 3.1.1 Common objectives of lab tests

This document presents the results of the laboratory tests that were conducted to:

1. examine the psycho-physiological reactions (e.g. heightened concentration or alertness, relaxation) triggered by light variables and how these reactions can be influenced by changing light parameters (lab tests at BLL)
2. define the target values for the control system by examining which psycho-physiological states accompany “successful” every-day events or activities (lab tests at BME)

The main aim of the laboratory tests at BME and BLL was to measure the psycho-physiological reactions, e.g. increased alertness or relaxation, of older people to light and lighting parameters such as contrast or intensity within one single closed room. These measurements were then to be correlated with the results obtained when test persons perform the activities or find themselves in previously defined situations.

Diary-based time use studies conducted by APOLLIS (Del. 1.1) revealed that time use in every-day life varies significantly with age. Total domestic work does not change very much with age. However, decreasing work loads due to smaller households are often offset by age-related impairments. The most significant differences can be observed when it comes to leisure activities (see Table below):

	<i>Cases</i>	<i>Mean daily hours</i>
<i>Watching TV</i>	171	2,6
<i>Relaxing at home</i>	131	1,9
<i>Going outside</i>	126	2,3
<i>Listening radio</i>	110	2,7
<i>Reading newspapers</i>	98	1,1
<i>Gardening/animals</i>	59	1,7
<i>Receiving visitors</i>	41	1,4
<i>Reading books</i>	35	1,6
<i>Reading magazines</i>	29	1,1
<i>Visiting someone</i>	20	2,0
<i>Exercise at home</i>	19	1,0
<i>Knitting</i>	18	1,8
<i>Solving puzzles</i>	15	1,1
<i>Outdoor exercise</i>	10	1,3
<i>Listening CD/records</i>	7	1,6
<i>Function/event</i>	7	2,1
<i>Crochet</i>	6	1,8
<i>Tailoring</i>	6	2,2
<i>Playing solo-games</i>	4	1,3
<i>Fitness/swimming</i>	2	2,5
<i>Computing/Internet</i>	2	1,5
<i>Handicrafts</i>	2	3,0
<i>Writing</i>	2	1,5
<i>Parlour games</i>	2	3,5
<i>Drawing/painting</i>	1	3,0

Source: apollis 2007

**Table 1: Average duration of daily activities APOLLIS (2007).**

Based on the results above the following most important visually demanding activities were identified and included in our „simulated home” experiments:

- *Watching TV*
- *Reading newspapers, books, magazines*

From the important activities, but visually not demanding activities the following were identified and used in the experiments:

- *Relaxing at home*
- *Listening to the radio (music)*
- *Receiving visitors (conversation, social activity)*

### 3.1.2 Selected biosignals

The following biosignals were measured in the laboratory tests:

- **Electromyogram (EMG)** refers to the electrical activity of muscle fibres (series of action potentials always precede mechanical activity of muscle fibres). This signal can be chosen, because high muscle tension often occurs under stress. Bias: The absolute level of the muscle tension however strongly depends on the muscle where it is measured. Individual adjustment of values has to be done.
- **Electrodermal activity (EDA)** is also referred to as skin conductivity or skin conductance (SC) and basically measures the electrical conductivity of the skin. The momentary fluctuations of EDA have been termed phasic responses (**skin conductance response – SCR**), whereas the relatively stable EDA is referred to as the tonic level (**skin conductance level – SCL**). Measures of SC can be interpreted as mainly reflecting changes in sweating activity. This signal was found to be a good and sensitive indicator of stress, as well as other stimuli, and helps to differentiate between conflict/no conflict situations. Bias: This signal is also influenced by external factors such as outside temperature. It therefore needs reference measurements and calibration.
- **Electrocardiogram (ECG)**. The ECG signal is the manifestation of electric activity of the heart. This can be recorded directly on the surface of the chest or alternatively on the limbs. Recording ECG from the limbs is less inconvenient but more vulnerable to artifacts. For the ALADIN system we decided to use the ECG from the chest to prevent the system being influenced by artifacts. It can be used to measure heart rate (HR) and **inter-beat intervals (RR)** to determine the heart rate variability (HRV).
- **Heart Rate Variability (HRV)**. The ECG is taken to examine the heart rate variability. This measurement provides information about relaxation and exertion/activation. In the condition of relaxation the heart rate tends to be more variable, whereas in the condition of exertion the heart rate is more constant. Measuring the time-intervals between two subsequent heartbeats captures the heart rate variability. If the time-interval is always the same, then there is no variability at all. This state occurs especially when people get excited or are exerted (are investing mental effort). A spectral analysis is carried out and the resulting mid frequency band is used for further analysis. A high HRV in the mid frequency band can indicate a state of relaxation, whereas a low HRV can indicate a potential state of mental stress or high workload. Taking also into consideration the related RR interval patterns, HPV-time function often provides more accurate estimation of relaxed or activated states. HRV together with the related RR interval patterns are also indicators for detection of sleep quality or sleep disorders.
- **Respiration**. Sensors measure how deep and fast a person is breathing. This is measured by applying a stretch sensor in a rubber band around the chest. Fast and deep breathing can indicate excitement such as anger or fear but sometimes also joy. Rapid and shallow breathing can indicate tense anticipation including panic, fear or concentration. Slow and deep breathing indicates a relaxed resting state while slow and shallow breathing can indicate states of withdrawal, passivity, like in depression or in calm happiness. In the experiments respiratory amplitude and respiration rate were used as parameters.

· **Reaction Time Tasks.** Remarks: while all the other parameters can be measured continuously, the reaction time (RT) is the result of a specific task and, by its very nature, is a discrete – although repeatable – value. Measures of reaction times via detection tests could be done before and after the activation situation. Extended reaction times will show an increase in general fatigue whereas shortened reaction times indicate alertness. Bias: Reaction times are influenced by other situative parameters and are not a measure of better activation or competence. E.g. reaction times are not significantly related with better driving competence.

In our tests, the Number Verification Test (NVT) was used to measure alertness.

### 3.1.3 Problems encountered

Although **medicine intake and diminished visual ability** had been originally defined as exclusion criteria for participation (see Deliverable 1.1), on the ground it proved extremely difficult to strictly adhere to these criteria since in the eligible target group both – medicine intake (including beta blockers) and diminished visual ability – are very common. This is why at BME the original pool of test persons of 57 had to be reduced to 30, whilst at BLL, it was decided to record any impairments rather than exclude potential test persons.

The influence of medicines on electrodermal activity and heart rate will have to be discussed with medical experts once the final results are available.

In Hungary, in particular, it proved difficult to find male test persons who were eligible. On the one hand, this is due to the fact that above the age of 65 the proportion of women is almost twice that of men, but also to the bad health status of many men. The final sample therefore consisted of 24 women and only 6 men.

Also, it turned out that the majority of older adults suffer from heart problems, which is why cardiac parameters were not considered reliable.

On the positive side it should be noted that sticking on the electrodes twice in the course of the tests as well as the repeated measuring of blood pressure proved to be without any problems.

## 3.2 Psycho-physiological lighting effects

### 3.2.1 Objectives

The main goal of Task 1.2 was to capture the psycho-physiological reactions of a representative number of test persons recruited from the target group triggered by certain light parameters in a laboratory setting. BLL then tried to establish correlations between light parameters as independent variables and physiological biosignals (blood pressure, heart rate, respiration rate, skin conductance and muscle tension), cognitive performance (continuous performance test) and subjective perception (rated by questionnaires).

The tests at Bartenbach Light Laboratory pursued two objectives:

- \_ Investigate the effects of different lighting situations on older adults in terms of psycho-physiological impact, subjective perceptions and performance.
- \_ Produce recommendations for the prototype lighting system to be installed for the field tests (WP4).

More specifically, the following questions were to be answered:

- \_ Are 250 cd/m<sup>2</sup> sufficient for activating older test persons?
- \_ Is a colour temperature of 4000K sufficient for activating older test persons?
- \_ Is there a difference between a colour temperature of 3000K and 4000K as far as its relaxing effect on test persons is concerned?
- \_ Is there a difference between 50cd/m<sup>2</sup> and 100cd/m<sup>2</sup> as far as their relaxing effect on test persons is concerned?

## 3.2.2 Description of tests

### 3.2.2.1 Socio-demographic profile of the test population

Fifteen test persons, 9 female and 6 male, participated in two test runs each. The average age was 69 (min: 65, max. 82). Only 2 out of 15 were wearing glasses; 8 test persons were taking medicines.

The participating test persons were paid 10 Euro per hour. The overall time of data collection per person was approximately 4 hours between 8.00 and 12.00 am. Before starting with data collection, it was verified if test persons fulfilled the selection criteria previously defined.

The laboratory study has been divided into two parts: the first is about testing eight different situations with unvarying lighting, four with dim and four with bright lighting (plus one standard normal lighting situation). The second part is concerned with the influence of dynamic lighting situations generated by genetic algorithms. This study followed a research design proposed by Kempter et al. (2005) in „Evolutionary feature detection in interactive biofeedback interfaces“ (see Footnote 1 for reference).

#### Part 1: Investigation of unvarying lighting situations

BLL aimed to test eight different lighting situations to find out if and to what extent these elicit psycho-physiological reactions in elderly people. These lighting situations take into account that older people tend to need higher light intensity stimuli and a larger part of the short wavelength spectrum of light for activation. For relaxation purposes, balanced light intensities within the field of view with a reduced short wavelength component of the light spectrum are required.<sup>3</sup>

The following lighting parameters are characteristic of these lighting situations:

Lighting	Colour temperature	Luminance (Illuminance)	Luminance ratio
„bright“	6500 K	500 cd/m <sup>2</sup> (2500 lux)	2:1
		250 cd/m <sup>2</sup> (1250 lux)	2:1
	4000 K	500 cd/m <sup>2</sup> (2500 lux)	2:1
		250 cd/m <sup>2</sup> (1250 lux)	2:1
„dim“	4000 K	100 cd/m <sup>2</sup> (500 lux)	1:1
		50 cd/m <sup>2</sup> (250 lux)	1:1

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<sup>3</sup> The same lightings were also applied at BME with the help of a standard lighting device designed by Bartenbach.

	3000 K	100 cd/m <sup>2</sup> (500 lux)	1:1
		50 cd/m <sup>2</sup> (250 lux)	1:1
„normal”/ „standard”	4000 K	150 cd/m <sup>2</sup> (750 lux)	1:1

*Table 2: The experimental conditions in BLL tests incl. lighting parameters applied*

The different lighting situations were implemented in a special-purpose, semi-circular light cabin (see Figure 2 below):



*Figure 2: The light cabin for producing different lighting conditions*

The aim of applying these different lighting situations was to test the following **hypothesis**:

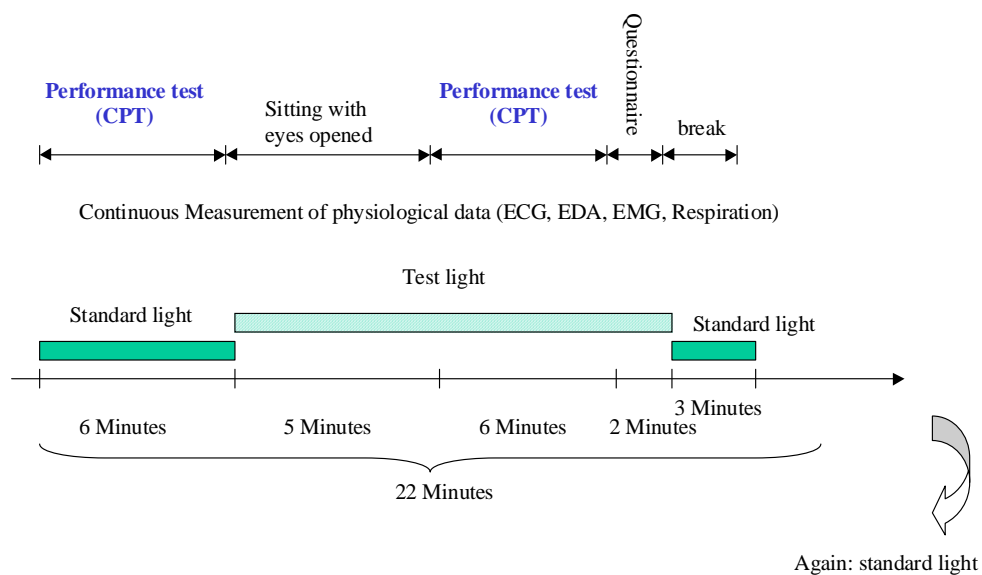
**With older adults, bright light (higher than 1200 lx) with high colour temperature (higher than 3900 K) elicits different psycho-physiological responses than dim light (lower than 600 lx) with low colour temperature (lower than 4100 K).**

The responses occur during a short time range of about 10 minutes.

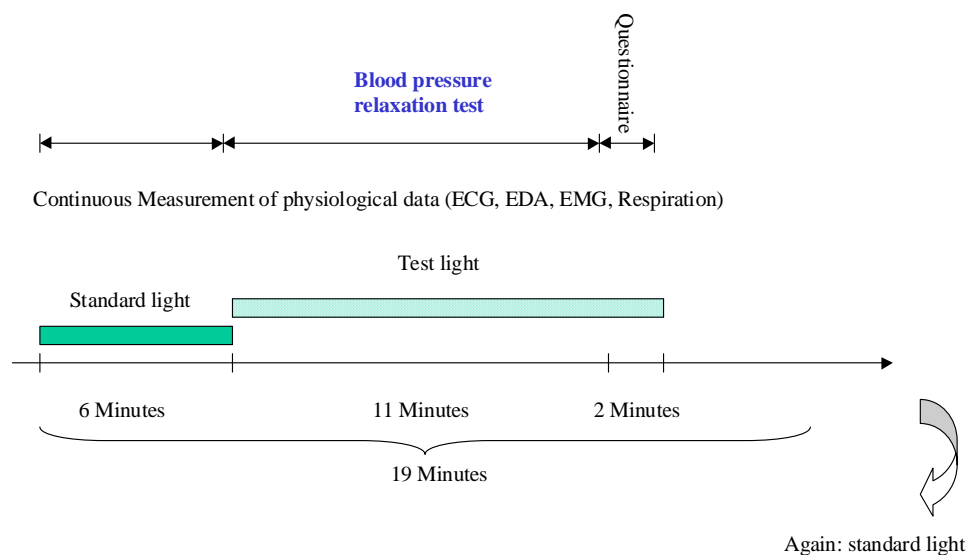
### 3.2.3 Implementation of tests

The data was collected within a time-span of approximately 2.5 hours by pair-wise random selection of bright and dim light situations (see Figures 3 and 4 below). The psychological activation of the elderly people is quantified as the difference of correct answers and reaction times in the continuous performance test<sup>4</sup>. First of all, the test has to be taken in standard lighting and repeated after five minutes' exposure to test lighting.

The psychological relaxation of elderly people is measured by collecting blood pressure data every minute and calculating a relaxation parameter out of the time-series of systolic blood pressure values.



**Figure 3: "Bright light" test procedure**



**Figure 4: "Dim light" test procedure**

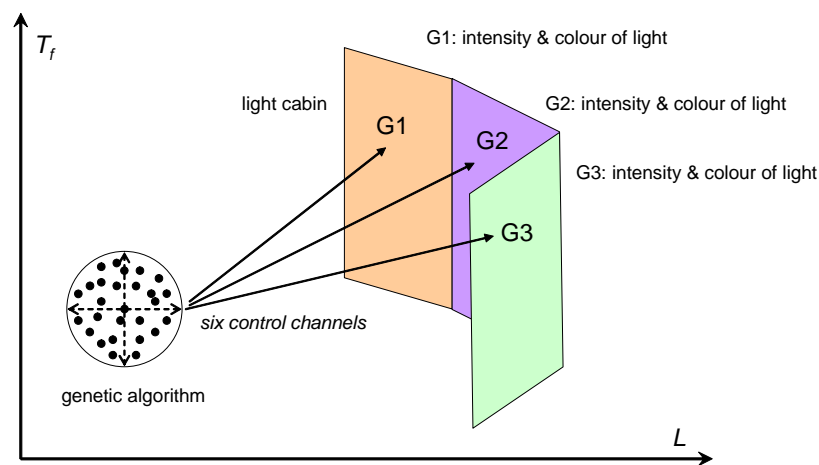
<sup>4</sup> See Mani, T. et al. (2005) Age-related decrements in performance on a brief continuous performance test. Archives of Clinical Neuropsychology, 20, 575-586.

Generally spoken, data collection consisted of psycho-physiological parameters gathered continuously or at discrete intervals (e.g. heart rate, respiration rate, electrodermal activity, muscle tension and blood pressure).<sup>5</sup>

In addition to the measuring of biosignals, a questionnaire was administered and a general performance test (continuous performance test) conducted.

## Part 2: Investigation of dynamic lighting situation

The second part of the laboratory experiments aimed at replicating a study done by Kempster et al. (2005).<sup>6</sup> In line with the principle of so-called “evolutionary lighting parameter detection” within an interactive biofeedback interface, elderly people were to be supported in their attentiveness during playing a memory game.



**Figure 5: Dynamic light generation (G1, G2, G3: three sides of light cabin)**

The tests were performed in the same light cabin as those in part 1 of this study. The genetic algorithm uses the whole range of lighting parameters, namely light intensity and colour of light. Since it is necessary that the three sides of the light cabin have to be controllable independently, the algorithm operates with six different lighting channels by DALI: G1, G2, and G3 each with light spectrum and light intensity. G1, G2, and G3 represent the three different sides of the light cabin.

All data collection was done at BLL. The psycho-physiological data (RR, SCL, SCR, EMG, Respiratory amplitude) were collected by the Varioport system provided by BMT. Since the txt output of the Varioport device was produced by 256 Hz sampling frequency, the output files were unnecessarily detailed for our present purposes. Therefore, BLL chose a final sampling frequency of 32 Hz. This still provides a temporal resolution which is considered sufficient for practical purposes. According to the distribution of work between BME and BLL the task of BME was to produce mainly general results, while the task of BLL was to produce more detailed specific results about the short-term effects of lighting. This explains why BME used a sampling frequency of only 1 Hz, whereas BLL applied 32 Hz.

5 For blood pressure relaxation test see Hecht, K. et al. (2001) Objektive Kontrolle der Selbstentspannungsfähigkeit anhand von Zeitreihenmessungen des Blutdrucks und der elektrodermalen Aktivität (EDA). In: Hecht, K. et al. (2001): Emotionaler Stress durch Über- und Unterforderung. Schibri-Verlag.

6 See Footnote 1).

### 3.2.4 Preliminary results

The main preliminary results can be summarised as follows:

#### **Test results with unvarying dim lighting:**

- The 4 different situations with dim lighting did not produce any differences in the blood pressure of the test persons.
- In the questionnaires, the lighting situation with 4000 K and 100 cd/m<sup>2</sup> was perceived as significantly less relaxing than the other three lighting situations.
- The impact on HRV of all four lighting situations differed significantly from that of standard lighting (4000K and 150 cd/m<sup>2</sup>).
- A HRV analysis did not show any significant differences between the 4 dim light situations.

#### **Test results with unvarying bright lighting:**

- The 2 bright light situations with 4000K and 500 cd/m<sup>2</sup> were perceived as significantly more activating, in the questionnaires, than those with 250cd/m<sup>2</sup>.
- The results in the continuous performance test (CPT) were significantly better for lighting situations below 6500K and 500cd/m<sup>2</sup> compared with standard lighting. The same tendency applies to 4000K and 500cd/m<sup>2</sup>. The CPT results for lighting situations of 250 cd/ m<sup>2</sup>, however, are not significantly better than standard lighting.
- When comparing the 4 different lighting situations, the CPT results of the ones with 500cd/ m<sup>2</sup> are significantly better than the ones with 250cd/m<sup>2</sup>.
- For high frequency (HF), the frequency analysis of heart rates shows a significant reduction when applying bright lighting of 6500K and 500cd/ m<sup>2</sup> compared with standard lighting.
- No comparable results, however, could be observed for the other 3 bright light situations.
- The HRV analyses did not differ between the first and the second day of the test run.
- Besides, the HRV data did not differ significantly between the 4 different bright light situations.

#### **Test results with dynamic lighting:**

- The number of correct pairs in the memory game were slightly higher in the dynamic light situations produced by genetic algorithms than in continuous light situations but the difference could not be proved with statistic significance.

Please note, however, that the physiological parameters have not yet been analysed.

## 3.3 Defining psycho-physiological target values

### 3.3.1 Objectives

**Target values** of indicators are based on individual baseline or reference values, representing an undisturbed natural state, an acceptable error margin, and are the ranges of indicator values we are aiming at. Thus these represent the criteria by which the performance or actual state (relaxed or activated) of the test person is judged.

Target values in electrophysiological measurements are the values which represent the desired state of alertness or relaxation. Target values can not only be fixed numeric values, but also desired trends (as increasing or decreasing) or local extremes (maxima or minima).

The psycho-physiological target value indicates the psychological state, which is associated with e.g. success in a well-defined situation.

As already said, the task of the Budapest University of Technology and Economics (BME), Department of Ergonomics and Psychology (BME) was to define the optimal psycho-physiological target values for the successful accomplishment of mentally/visually demanding (VDT) every-day activities. The intention was to operationalise the mental and physical fitness e.g. alertness or relaxation by measurable indicators as blood pressure, heart rate, respiration rate, skin conductance, ECG, body temperature etc.

As a result of various discussions among partners about the implementation/functions of the Aladin prototype it was decided to shift the focus from situations and activities to the states of activation and relaxation, since most activities and situations can be associated with either state, e.g. for some people cooking a meal is a stressful activity whereas for others preparing a five-course dinner may help them relax.

### 3.3.2 Description of tests

The final sample consisted of 30 test persons, 24 women and 6 men. The low number of males was due to the bad health status of men as well as their low representation in this age group (see 3.1.3 Problems encountered). The age range was between 65 and 84, with an average of 71 years. Before starting with data collection it was verified if test persons fulfilled the selection criteria previously defined.

All data collection was done at BME. The overall time of data collection per person was approximately 4 hours between 8.00 and 12.00 am.

The laboratory study has been divided into two parts: the first part investigates **psycho-physiological target values** through interviewing and observing older people performing some typical activities in simulated homes. During these activities psycho-physiological signals are continuously measured.

The second part deals with additional experiments that measure the influence of the lighting spectrum on the habituation of orientation reaction on the one hand and the psycho-physiological signals during dynamic lighting on the other.

## Part 1: Investigation of psycho-physiological target values

BME measured the heart rate, the skin conductance, the muscle tone as well as the respiratory amplitude. For this purpose, the Varioport system provided by BMT was used to find psycho-physiological indicators for mental activation and relaxation. The laboratory experiments were conducted under the same lighting conditions as in the BLL tests. The psycho-physiological measurements were made with the following situations:

Classification	Situations	Colour	Luminance
Extreme relaxation ↑ ↓ Extreme Activation	Lying down relaxed with eyes closed.	2700 K	20 cd/m <sup>2</sup> (100 lux)
	Lying down relaxed with eyes open.		
	Sitting relaxed with eyes open.		
	Sitting and watching a „calm” nature video.		
	Sitting and watching an „exciting” nature video.		
	Standing up from sitting and stay standing.		
Sitting and performing VDT task as quickly and as accurately as possible.	8000 K	450 cd/m <sup>2</sup> (2000 lux)	

*Table 3: The experimental conditions in BME tests (situations).*

The tests were performed in a special-purpose simulated home:



*Figure 6: The equipment used in the BME tests*

The aim of applying these situations was to find answers to the following **hypothesis**:

**With older adults, relaxing situations are accompanied by different psycho-physiological signals than activating situations.**

The responses occur during a short time range of about 10 minutes.

### 3.3.3 Implementation of tests

The data were collected within an approximately 2.5 hours period by pair-wise random selection of bright and dim light situations (see Figure 7 below).

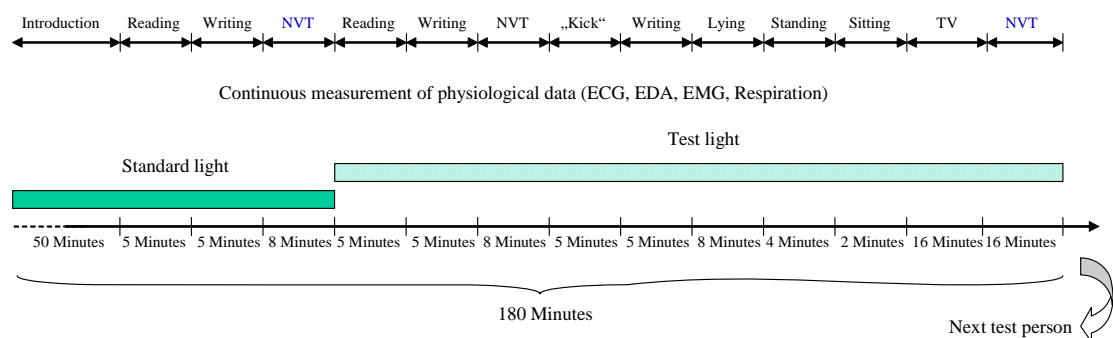
The test starts with an introduction, agreement to participate, sticking on the electrodes (heart rate, skin conductance, electromyography, and respiratory movements), and choosing a lamp from several proposed lamps that he/she judges similar to his/her lamp used at home.

Under the “home lamp” condition test users perform an every-day normal visual activity (reading a newspaper article from a set of photocopied articles) without being interrupted. Afterwards, they fill in a questionnaire including a semantic differential scale with consists of 6 six-point scales: like - dislike, comfortable - uncomfortable, too bright - too dim, easy to read - difficult to read, pleasant light colour - unpleasant light colour.

They also answer the question if they would you like to have this kind of lighting available for everyday reading – yes or no. Finally, they perform the Number Verification Test (NVT) on a computer.

After that the test lighting conditions start. With luminaire 1 (FQ 54/840 4000K, „normal”) above the table (~1300 lx on the table) the test person starts reading again, fills in the semantic differential (writing) and does the Number Verification Test (NVT). After 5 minutes of further reading under the “normal” lighting provided by luminaire 1 (FQ 54/840 4000K, „normal”) the illuminance/luminance level is suddenly increased to well above the normal comfort zone but still below the uncomfortable glare. This is achieved by switching on the additional luminaire 2 (FQ 54/827 2700K, „relaxing”) and luminaires 3 and 4 (both: FQ 54/880 8000K, „activating”). The test person goes on reading. After the radical increase all luminaires are set at maximum (~5000 lx on the table); this is called “strong” (“horse kick”) lighting.

Aim: to check if this increase has any considerable effects on the measured psycho-physiological parameters. The subjective perception was registered by the same differential scale as above.



**Figure 7: Target value test procedure**

With luminaire 2 (FQ 54/827 2700K, „relaxing”) in use (directed at the ceiling with ~100 lx on the floor), the test person is lying on a bed for 4 minutes with eyes closed, 4 minutes eyes open. He or she then stands up and stays standing for 4 minutes (physiological „fitness test”), followed by relaxed sitting before the standard LCD screen to be used for simulated TV watching and the number verification test later.

The test person is then presented with a short calm and a (moderately) exciting nature video in random order. After that the test person performs the computerised version of the NVT under two different lighting conditions - “relaxing” and “strong”- provided by luminaire 2 (FQ 54/827 2700K, 125 lx / 25 cd/m<sup>2</sup> „relaxing”), and luminaires 3 and 4 (both: 2×FQ 54/880 8000K, 2500 lx (500 cd/m<sup>2</sup> „activating”), respectively, in random order.

## **Part 2: Additional laboratory experiments**

The study for analysing the **influence of lighting spectrum on the habituation of orientation reaction (ORI)** aims at testing the *hypothesis that* strong blue lighting (with a maximum of about 470 nm) produces a marked increase in activation in comparison with dim red lighting. This difference is reflected in different habituation characteristics of orientation reaction.

The study of **dynamic lighting** aims at testing the hypothesis that dynamic lighting with carefully chosen parameters has an impact on the test persons’ activation level. This means that dynamic lighting with seemingly „ever-increasing” (or „ever-decreasing”) illuminance can be used to increase (or decrease) the users’ activation level as reflected in objective psychophysiological parameters, in objective NVT (Number Verification Test) results, and also in subjective opinions received on semantic differential (SD) rating scales. Besides, in a simple „doing nothing” relaxation task the colour of light (blue or red) should have an influence on HRV.

All psychophysiological data (RR, SCL, SCR, EMG, Respiratory amplitude) were collected with the Varioport system provided by BMT. Since the txt output of the Varioport was produced by 256 Hz sampling frequency, these output files were unnecessarily detailed – and thus also too large - for our present purposes. Therefore, in accordance with our earlier decision, the final sampling frequency was set to 1 Hz and the files produced this way were used in the final data processing instead of the original Varioport files. In order to produce spectral parameters from RR raw data, these data were also converted into the psd format of our ISAX system for further processing. Apart from spectral parameters, another reason was to produce files in psd format. This way BME was able to use the sophisticated artefact correcting facilities of its ISAX system, which has also proved useful in the case of the RR parameter.

A computerized version of the Number Verification Test (NVT) was used to characterize the *performance* of the test persons under well-defined conditions. The used NVT parameters were: NVT hit numbers in 30/60/90 sec window and NVT hit ratios in 30/60/90 sec window that were automatically calculated and recorded during the experimental sessions.

The *subjective measures (opinions, feelings)* were collected on appropriate scales. As the final data processing and statistical analysis was done with the *SPSS for Windows 14.0* package, finally all the data above were converted into SPSS sav files.

### **3.3.4 Preliminary results**

The main results can be summarised as follows:

#### **Test results with relaxing condition:**

- When comparing the three different relaxing situations the heart rate is significantly lower the more relaxing the situation. However, the absolute difference in heart rate is very small.
- For mid frequency, the frequency analysis of heart rates shows no significant reduction in line with higher level of relaxation.

- The skin conductance level shows no significant reduction in line with higher level of relaxation.
- When comparing the three different relaxing situations the skin conductance response is significantly lower the more relaxing the situation. Most possible pairwise differences are significant. The variance analysis for repeated measures (ANOVA) also results in significant differences.
- Lower subjective activation rating scores are mainly associated with lower skin conductance responses. The majority of the possible pairwise differences are significant. The variance analysis for repeated measures (ANOVA) also results in significant differences.

**Test results with activating condition:**

- When comparing the three different activation situations the heart rate is significantly higher the more activating the situation, but absolute difference in heart rate is very small.
- For mid frequency, the frequency analysis of heart rates shows no significant increase in line with higher level of activation.
- The skin conductance level shows no significant reduction in line with higher level of relaxation.
- When comparing the three different activating situations the skin conductance response is significantly higher the more activating the situation. The majority of the possible pairwise differences are significant. The variance analysis for repeated measures (ANOVA) also results in significant differences.
- Higher subjective activation rating scores are mainly associated with higher skin conductance responses. The majority of the possible pairwise differences are significant. The variance analysis for repeated measures (ANOVA) also results in significant differences.
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**Additional results:**

- Skin conductance response during Number Verification Test (NVT) is significantly higher with 450 cd/m<sup>2</sup> (2000 lux) and 8000 K (bright lighting) than with 20 cd/m<sup>2</sup> (100 lux) and 2700 K (dim lighting).
- Skin conductance response during reading is significantly higher with 450 cd/m<sup>2</sup> (2000 lux) and 8000 K (bright lighting) than with 20 cd/m<sup>2</sup> (100 lux) and 2700 K (dim lighting).
- The dim light (20 cd/m<sup>2</sup> 2700 K) is judged as very relaxing and very pleasant by the test persons.
- The bright light (450 cd/m<sup>2</sup> 8000 K) is judged as too bright and very activating by the test persons.

The illuminances produced by the lamps selected by the test persons were very different – the range was from 100 lux to 1500 lux on the table.

The detailed results of these additional laboratory experiments will be placed on the project platform ([www.ambient-lighting.eu/confluence](http://www.ambient-lighting.eu/confluence)) since they are beyond the immediate scope of the ALADIN project.

## 3.5 User tests

### 3.5.1 Objectives

In line with our participatory approach, we have also carried out the first user tests with a very simple version of the GUI interface for the ALADIN prototype. Based on a series of discussions with experts (e.g. staff of nursing homes) and end-users, i.e. the older people themselves, it emerged that a TV set can be found in almost all households of older adults and that therefore it can be assumed that our target users are familiar with handling remote controls. Therefore it was decided to use a computer with added TV functionality for implementing the adaptive lighting system.

This, however, poses new challenges since watching TV is characterised by a “lean back” attitude whereas working on a computer is normally associated with a so-called “lean forward” attitude. The human computer interface has been conceived with an active user in mind whereas TV systems are traditionally aimed at passive consumers. This is why the design of the interface has to take into account not only general usability and accessibility guidelines, but has to pay attention to the specific requirements of TV screens.

A TV screen is normally placed at a distance of a couple of meters from the viewer and has a lower resolution than a computer. Besides, when designing the screen layout we cannot use the full screen because TV sets vary in terms of the screen size used for presentation. The so-called “safe area” can be reckoned to be about 10% smaller than the full screen, or about 576 x 460 pixels.

### 3.5.2 Description of tests

We designed a simple user interface in line with the widely accepted accessibility guidelines of WCAG 1.0. On the start page the users can select from a menu consisting of the various components of the prototype.

After several expert reviews, tests were conducted with eight end-users between the ages of 60 and 84, 2 men and 6 women, using the ‘thinking aloud’ method.



*Figure 8: ALADIN user interface with common TV screen and remote control*

### 3.5.3 Preliminary results and outlook

Several general observations can be derived from these first user tests:

- The majority of users prefer number keys to cursor keys.
- Users expect immediate confirmation or feedback from the system.
- Concepts such as biofeedback are not known and will have to be replaced.
- Users like the overall graphic design (font, colours, contrast) and find the GUI easy to navigate, provided that the number of navigation elements is kept to a minimum. Similarly, the number of menu items to choose from should not exceed 5 or 6 items.

The feedback obtained has been incorporated into the redesign. The next user tests to be carried out (October 8-10) will focus on the visualisation of the biosignals and the advice application including the virtual agents.

In WP4 „User testing und evaluation“ we shall take the ALADIN prototype to real-life testing grounds and test it with approximately 12 pilot users contributed by our senior citizen representatives. BLL, LMU-Muenchen, APOLLIS and FHV will install the ALADIN prototype in at least 3 households of single senior citizens or single room in senior residence in 4 locations for a duration of approximately 3 months. This is to evaluate the fitness for purpose of the prototype as well as the impact of ALADIN on the mental/physical fitness and wellbeing of the test persons.