Appropriate Dynamic Lighting as a Possible Basis for a Smart Ambient Lighting

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Abstract. The objectives of this empirical study were to contribute to the development of an intelligent, adaptive home lighting system for the elderly. The basic idea was that a carefully chosen dynamic lighting with seemingly ever-increasing ("up") - or ever-decreasing ("down") - illuminance can be used to increase (or decrease) the users' activation level as they wish, a change that will be reflected in objective psychophysiological parameters, in objective performance, and also in subjective feelings. The paper examines the effects of two particular different forms of dynamic lighting – having the same average illuminance over time – on the performance of the *number verification task* (NVT) by older adults. As a group, the older adults showed no difference between the two forms of dynamic lighting. However, by involving the individual's sensation seeking needs it was shown that the kind of dynamism influences both the subjective preferences and the objective visual performance. These findings emphasize the importance and sensitivity of individual characteristics of the elderly and have to be taken into consideration for the design of adaptive lighting systems.

Keywords: AAL (ambient assisted living), ambient lighting assistance, dynamic lighting, sensation seeking needs.

1 Introduction: The Concept of the ALADIN Project

This paper is a summary of the main results of our dynamic lighting experiments carried out in the frame of the ALADIN project (Ambient Lighting Assistance for an Ageing Population), the basic concept of which can be seen in Figure 1.

According to the Description of Work [1] ALADIN aims at developing an intelligent assistive system based on ambient lighting to support mental alertness and memory performance as well as relaxation in specific situation. As described here, the system is also expected to assist with regulating circadian rhythms.

The ALADIN prototype aims at enabling the users to make adaptations tailored to their specific needs and wishes by developing an intelligent control system that is capable of capturing and analysing the individual and situational differences of the psycho-physiological effects of lighting, and – based on it - is also capable of providing the users with specific adaptive lighting inputs that fit their actual needs and wishes.

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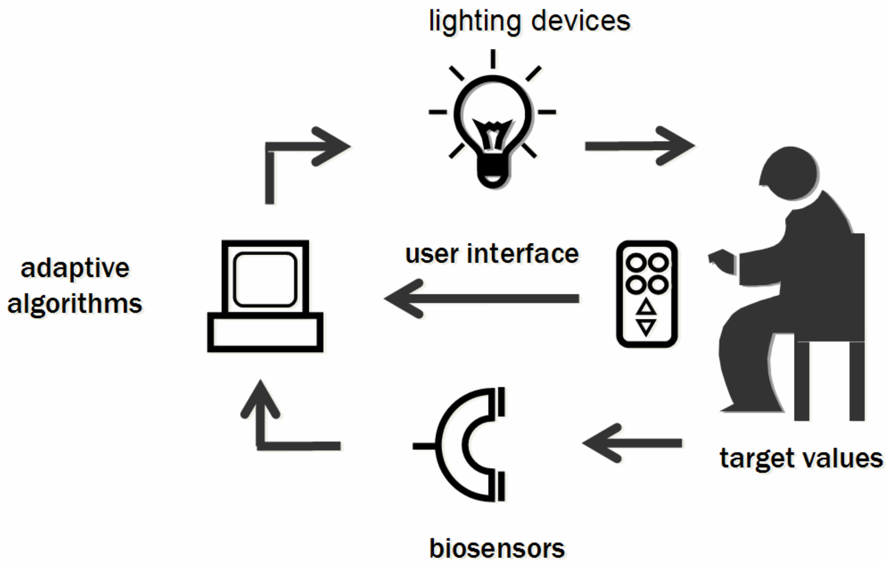

Fig. 1. The basic concept of the ALADIN project

2 The Concept of Dynamic Lighting

Dynamic lighting is, by our definition, lighting that provides light output parameters varying over time with a variation that can be perceived by people. The varying lighting parameters can be illuminance or spectral characteristics or both.

As natural lighting is almost always dynamic, there are probably biological evolutionary mechanisms in humans that make them prefer varying lighting rather than fixed lighting. The basic idea behind the desire to use dynamic lighting is that dynamic lighting with carefully chosen characteristics could induce better performance and lower strain at the same time. A correctly timed change in illuminance or color temperature will periodically stimulate the arousal that otherwise would have decreased under fixed lighting due to processes such as habituation, fatigue, monotony, or saturation. Some lighting system manufacturers – as Philips [2] - already provide dynamic lighting systems.

In previous studies carried out at the Budapest University of Technology and Economics, we - Izsó and Majoros [3], Majoros [4], Izsó [5] - conducted laboratory experiments studying the effect of dynamic lighting on the visual performance and the related feelings of young people. These results showed that, compared to fixed lighting:

- dynamic lighting of the same average illuminance leads to a better quality of visual performance, i.e., more accurate work, although there is no difference in the quantity of work
- dynamic lighting is judged significantly as more stimulating, more pleasant and less tiring
- dynamic lighting produces higher levels of arousal in physiological terms.

This paper reports a series of new laboratory experiments aimed at identifying the effects on performance and subjective feelings induced by two selected dynamic lighting conditions in older adults. Dynamic changes referred to illuminance, changes in spectral characteristics were not studied.

3 Method

3.1 Setting, Participants and Sessions

The experiments were carried out in the Indoor Ambient Environment Laboratory of the Budapest University of Technology and Economics. 12 participants were hired (8 females and 4 males), their age ranged from 66 to 84, with an average of 71. The time of sessions was always between 13.00 pm - 17.00 am.

The procedure and timing for each experimental session was as follows:

- Applying the electrodes and giving instructions (8-10 min).
- Performing the computerized version of the number verification task (NVT) for 2×16 minute periods (covering 4 cycles of dynamic lighting) - with a 4 minute break in between – under one form of dynamic lighting (36 min). During the break the illuminance was 200 lx .
- Completing two subjective rating scales, and giving his/her opinions about the lighting verbally (10-12 min).

The NVT (*Numerical Verification Test*) was used as an objective measure of visual performance. Several authors – e.g. Rea [6], Rea et al. [7] - have already described the development and implementation of the NVT as a tool for measuring visual performance as a function of different lightings.

We used the NVT hit ratio (the ratio of the number of successful hits to the total number of hits) as a parameter of performance *quality* and the NVT absolute hit number (the total number of hits) as a parameter of performance *quantity*. It is known from "speed/accuracy trade-off" studies that during performing particular tasks a lot of factors influence if a person sacrifices accuracy for speed, or the contrary. Some persons optimize their performance for speed, others for accuracy. Therefore it is important to use both speed (*quantity*) and accuracy (*quality*) as performance measures simultaneously. This is the reason why both NVT hit ratio and NVT hit number were used. These measures were automatically calculated in three different window sizes. The data corresponding to the 60 s window was used in this study.

Since the NVT task was very simple and the participants had practiced it before, the possibility of a "learning effect" could be excluded. It was enough to avoid "carry-over" effects by conducting the "down" and the "up" sessions on different days.

The following psychophysiological measures were recorded during the sessions: the time interval between successive R waves of the electrocardiogram and its variance, the skin conductance level, the skin conductance response, the electromyogram and the respiratory amplitude. The two subjective rating scales used were the "relaxation" scale and the "pleasantness" scale. These are five-point scales but in our case half-points were also possible, so in effect we had 10-point scales. The anchor labels of the two scales were:

1: “perfectly relaxing, calming lighting”
2: “rather relaxing, calming lighting”
3: “neutral lighting between relaxing and activating”
4: “rather activating, stimulating lighting”
5: “perfectly activating, stimulating lighting”
And
1: “perfectly pleasant lighting”
2: “rather pleasant lighting”
3: “neutral lighting between unpleasant and pleasant”
4: “rather unpleasant lighting”
5: “perfectly unpleasant lighting”

In addition to the use of these two scales, the Sensation Seeking Scale (SSS) – Zuckerman [8], [9], [10], [11] - was also applied as a standard personality test for describing the sensation/stimulation seeking disposition of the participants. We used the second Hungarian version of SSS (form IV), based on more extensive factor analyses, contained four subscales:

1. Thrill and Adventure Seeking: The desire to try risky sports or activities involving elements of speed, movement, and defiance of gravity.
2. Experience Seeking: The desire to seek experience through the mind and the senses; through music, art, travel, and an unconventional style of life with unconventional friends.
3. Disinhibition: The desire for or actual enjoyment of uninhibited and socially extraverted activities, e.g., parties, social drinking, and a variety of sexual partners.
4. Boredom Susceptibility: A strong aversion to monotony or a lack of change, and a preference for the unpredictable; restlessness in confining, dull conditions.

The SSS score is simply the sum of the scores given on the four subscales.

3.2 Lighting Manipulations

The programmable lighting system applied consisted of six Zumtobel/Luxmate RCE 2×58 W mellow light luminaries arranged in a regular array. The CCT was 3000K and the CRI was 85%. The illuminance – time functions of the suddenly decreasing (“down”) and the suddenly increasing (“up”) dynamic lighting are shown in Figure 2.

In both cases the illuminance on the desk changed consistently between 300 lx and 900 lx, with an average of 600 lx. In the “down” condition the duration of the sudden decrease was 6 s, the length of both stable periods was 60 s, and the length of the slow increase was 354 s. In the “up” condition, the duration of the sudden increase was 6 s, the length of both stable periods was 60 s, and the length of the slow decrease was 354 s. Thus, for both “down” and “up” conditions, the total cycle time was eight minutes (480 s). As the whole session contained four complete cycles, the participants were expected to perform the NVT task for 32 minutes (1920 s) with a four minute break in the middle. This way the test persons received the same light exposure during the two sessions, but with different dynamics. These time parameters were determined so that the short 6 s down and 6 s up periods were clearly perceived by every participant, but the 354 s up and down changes were not.

3.3 Hypotheses

Based on our earlier studies - Izsó and Majoros [3], Majoros [4], Izsó [5] - it was taken for granted that either form of dynamic lighting would lead to better quality NVT performance than the equivalent fixed lighting. Our present hypothesis was simply that the form of dynamic lighting influences both the subjective preferences and the objective NVT performance. More specifically, it was assumed that the sudden brightening, the "up" dynamic lighting, would be subjectively preferred to the sudden darkening, the "down" dynamic lighting, and therefore would induce better NVT performance. This hypothesis was tested using subjective judgments and the overall NVT performance measures.

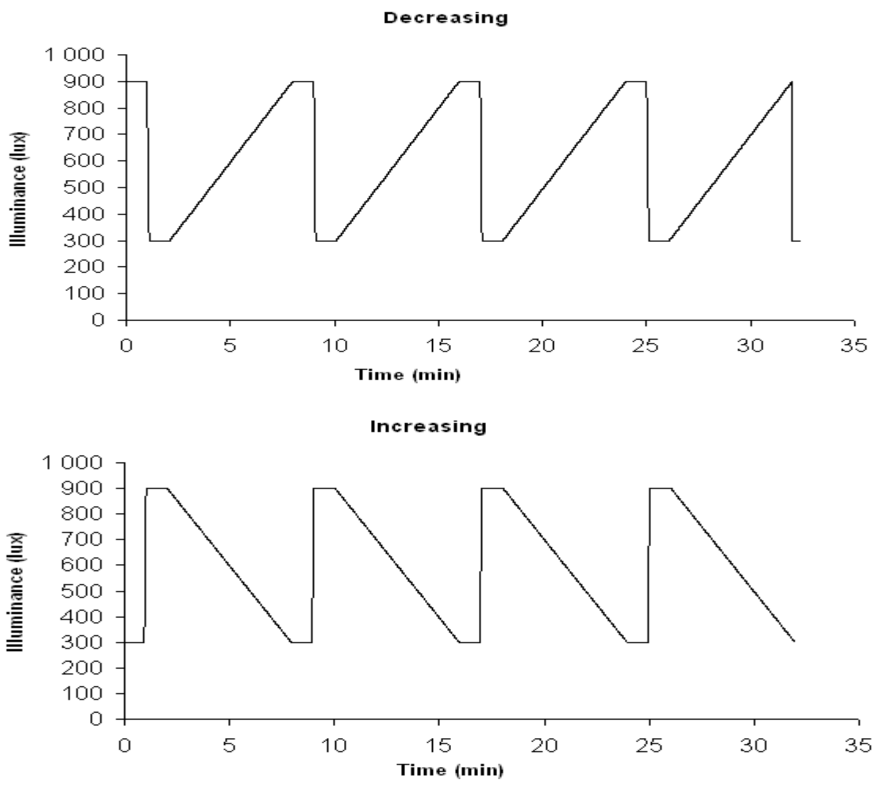

Fig. 2. The illuminance – time functions of the suddenly decreasing ("down", first graph) and the suddenly increasing ("up", second graph) dynamic lighting conditions

4 Results

Contrary to our hypothesis, neither the mean NVT hit number nor the mean NVT hit ratio showed any statistically significant difference between the "down" and "up"

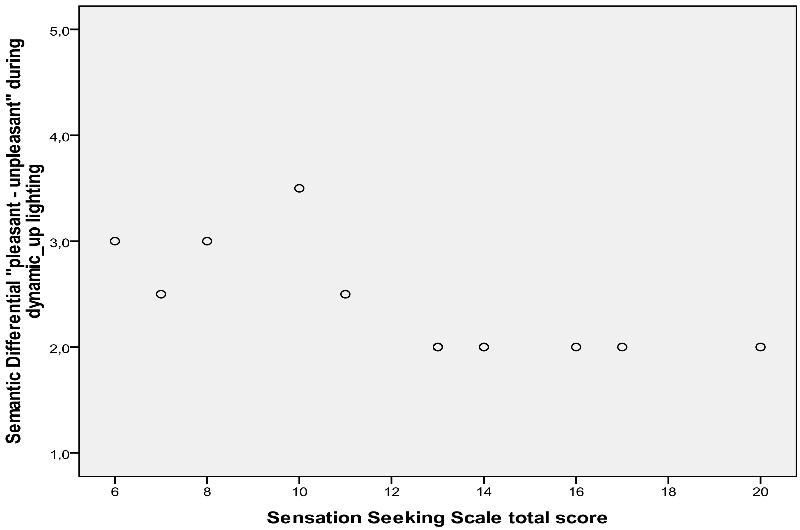

Fig. 3. The individual pleasant – unpleasant scores during the "up" lighting condition as a function of individual SSS scores (r = -0.720, p = 0.008)

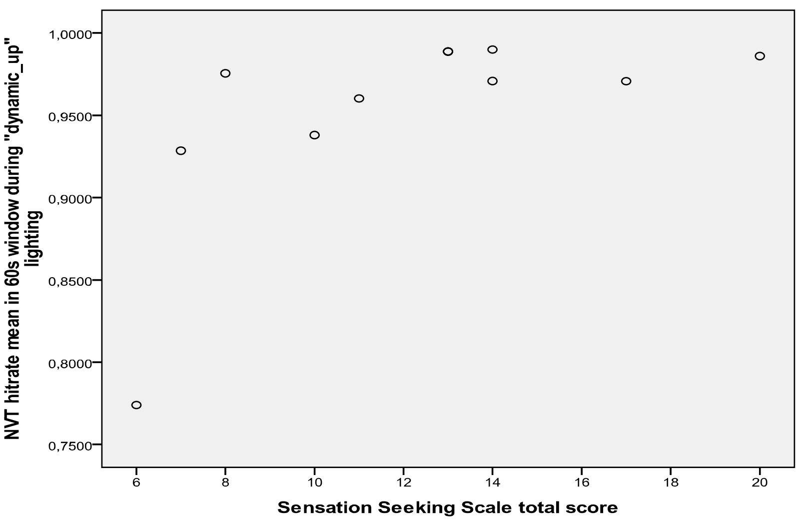

Fig. 4. The individual mean NVT hit ratio during the "up" lighting condition as a function of individual SSS scores (r = 0.617, p = 0.043)

forms of dynamic lighting. The only statistically significant effect found was that the standard deviation of the NVT hit number was higher during the "up" lighting condition than during the "down" lighting condition (Wilcoxon test, p=0,012). This indicates that the mean hit number was somewhat more uneven during the "up" lighting condition.

These results first seem to be "disappointing", but if the individual differences in sensation seeking, as measured by the SSS score, are taken into account, the overall picture becomes more complex but makes also more sense at the same time. For the "up" form of dynamic lighting, the individual SSS scores were correlated with both the pleasant – unpleasant scores (Figure 3) and the mean NVT hit ratio (Figure 4). These correlations are such that the participants with higher SSS scores found the "up" lighting more pleasant and performed better during "up" lighting in terms of NVT hit ratio than those with lower SSS scores.

5 Discussion and Implications for Practice

Neither the mean NVT hit number nor the mean NVT hit ratio showed a statistically significant effect of the form of dynamic lighting. However, when SSS scores are also considered, it was apparent that the young participants used earlier had much higher SSS scores (13 – 30) than the older adults used here (6 – 20). As shown in Figure 3**,** all older adults with SSS scores of 12 or higher rated the "up" lighting condition as pleasant. Assuming that the same or a similar relationship holds for the young people used in our earlier studies, who all had SSS scores of at least 13, it is obvious (Figure 3 and 4) why they all strongly preferred the "up" lighting to "down" lighting. Taking thus into account our elderly persons' SSS scores makes the overall picture even more understandable. The fact that during the "up" lighting condition people with higher SSS scores found the lighting more pleasant, and – consequently - also produced better NVT hit ratio, can be explained by their increased need for sensation.

The objective of our empirical study was to contribute to the development of an intelligent, adaptive ambient home lighting system for the elderly. The basic idea was that an appropriate dynamic lighting with seemingly ever-increasing ("up") - or ever-decreasing ("down") - illuminance can be used to increase (or decrease) the users' activation level as they wish, a change that will be reflected in objective psychophysiological parameters, in objective performance, and also in subjective feelings. We consider our finding that the impact of dynamic lighting is moderated by the individual's sensation seeking needs as important for the design of future adaptive lighting systems, especially for the elderly. Namely, our experiences have shown that while practically all the young people involved in our earlier experiences had relatively high SSS scores and therefore all preferred the "up" dynamism, among the elderly the SSS scores are globally lower and distributed so that a part of the elderly also enjoys the "up" dynamism, but an other part of them definitely does not.

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