SYNESIS
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Implementing ambient assisting technologies in elder-care: Results of a pilot study

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Abstract

The residential lighting conditions of elders are an important but frequently neglected aspect that may directly or indirectly influence important health and wellbeing parameters. Within the EU-funded project Ambient Lighting Assistance for an Ageing Population (ALADIN) a new adaptive lighting device that is capable to adapt to psycho-physiological parameters of an elderly person has been developed and pilot-tested under real life conditions. The main outcome criteria of this pilot study comprise wellbeing, life quality, mental and physical fitness as well as sleep quality. The system was installed in the habitations of twelve subjects and evaluated for three months in a field-test with technological support provided on demand. Results indicated a significant increase of wellbeing, life quality and mental fitness. However, these results may not only be attributed to the influence of the lighting system. Social contacts due to participation in the study and the introduction of new technologies might also be responsible for the positive outcome concerning wellbeing and life quality. Therefore, the potential of ambient assisting technologies for improving the lives of the elderly could be further developed by embedding them into social settings and facilitating social contacts rather than understanding them as technological stand-alone solutions.

Key words: ambient assisted living, geriatrics, residential lighting, psychophysiology, technology, aging, ageing

Introduction

The aging populations of societies in most western countries necessitate new solutions for both improving the wellbeing of seniors, and health care costs. Two distinct factors lead to an increased percentage of elderly in western societies. First, the life expectancies are steadily lengthening as a result of enhanced health care, and second birth rates (and therefore the percentage of young) are declining. This is evident in Germany and other European countries (1, 2) as well as for the United States of America, although in the USA more young immigrants and higher fertility rates counterbalance the aging of society (3). In light of these aging trends, new solutions must be found to increase independent living in advanced age, and reduce elders need for a fulltime assistance in nursing homes (4). The challenge is to find ethically and economically justifiable ways that can meet the various challenges associated with higher demands for expensive and resource-burdening long-term care. We posit that one possibility is to maintain elders' independence and autonomy by supporting their capacity for activities of daily living through the provision and use of ambient assistive technologies (AAT).

European approach to face the sociodemographic change

Toward this goal, the European Union has established a program called "Ambient Assisted Living" (AAL) as a collaborative research endeavor to find new technological solutions that enable independent lifestyles for disabled and/or elder persons (with or without chronic diseases). These technologies are designed to support and assist their users, i.e., especially elderly people, in their daily activities, and also reduce potential risks in households (such as falling, the inability of elderly persons to recognize or report medical emergency conditions). "Intelligent" technologies that have been designed for an aging population may contribute to preserving health and promoting independence, and may rightwardly shift the need and period for residential care. AAL relates to concepts, products and services that combine and improve new technologies and social environments with the specific aims of 1) increasing life quality for people in all periods of life, 2) providing assistive systems for healthy and independent living of elders.

Ambient Lighting Assistance for an Ageing population (ALADIN)

ALADIN was developed as an interdisciplinary, EU-funded AAL research project to: 1) investigate the subjective needs and demands of older persons with particular focus upon the lighting and luminance conditions of their homes; 2) develop a lighting prototype that is able to continuously adapt to the psycho-physiological condition of elderly people according to specific activities such as engaging in household chores, reading, or relaxing; 3) study the impact of adaptive lighting systems on health-related parameters.

The ALADIN project was conducted as a joint venture of seven European institutions from five European countries. Participating institutions were either academic research institutions or business-solution providers in market research, software development, and/or health care technology development.

Only recently has research interest come to focus upon the age-dependency of lighting conditions (5-7). Light is recognized to be important to wellbeing and health (8); this is especially the case for elderly people, because of physiological changes associated with the aging of the visual system, (i.e., yellowing of the lens, decreased flexibility of pupillary adjustment, and ophthalmic diseases such as cataract and glaucoma) (9). As well, age-related changes in circadian rhythm were considered to potentially benefit from particularly designed lighting systems (7, 10). The elderly often spend more time indoors that may lead to reduced exposure to important wavelengths of the sunlight (i.e., short wavelengths with at/about 460 nm that affect the release of melatonin and other neuromodulators) (11, 12). Daytime melatonin suppression is however not only important to maintain high sleep quality, but may also reduce daytime lethargy and increase general activity and cognitive performance levels (13-16). Correspondingly, wellbeing and life quality were identified as important outcome criteria for designing the ALADIN prototype; physical and mental fitness were determined as secondary outcome criteria.

Technological description of the ALADIN prototype

The ALADIN prototype consists of three components:

1. an adaptive control circuit and biofeedback system that can adapt various light parameters such as intensity, light distribution or color, in response to inputted psycho-physiological data (i.e., heart rate and skin conductance), which are registered continuously by smart sensors and wirelessly transferred to an adaptive feedback system,
2. a manual control system that can be adjusted via a graphical user interface (GUI: see Figure 1); and
3. an advice and support application that offers information based on the most recent findings about the factors that influence subjective wellbeing, mental alertness and physical fitness. The prototype of the ALADIN system was developed in the first year of the project based upon results of a dedicated demand analysis (17). Elders were involved in the development of the software, and were invited to provide feedback used in subsequent stages of development. The system was tested from January until August 2008 and evaluated in twelve households in Germany (Bad Tölz), Austria (Innsbruck, Dornbirn) and Italy (Bolzano) under "real life" conditions[i].

Objectives of the study

As ALADIN was designed to foster wellbeing, fitness and related health parameters, the study strove to scrutinize whether the ALADIN prototype design was able to demonstrate the predicted outcomes under realistic conditions.

Figure 1: Graphical User Interface of the ALADIN system with six menu points to choose of (in order from 1 to 6: watching TV, automatic light, manual light, exercises, history, tips for wellbeing. (Becker U, Kempter G, Maier E, Ritter W. Image source Apollis © European Union, with permission) [ii].

Method: Description of the ALADIN project

The initial survey in Bolzano

A first step for devising a prototype was to conduct demand analysis to investigate the needs of the target population. Both quantitative and qualitative data were gathered, and individual data collection from individuals in the target group was designed so as to not exceed 60 minutes. In total, 196 elderly people from South-Tyrol, aged at least 65 and (preferably) living on their own, participated in the requirements' analysis. For this study a quota sample for age, sex, language (Italian, German or Ladin/ Rhaeto-Romanic), and place of residence was drawn. Interviewers were free in identifying and selecting test-persons (TPs) in accordance with the quota and the inclusion criteria.

Subjects were asked to assess their current and optimal (i.e., most desirable) lighting conditions as well as their readiness to employ new technologies. In total, 92.9% (n = 182) of the interviewees stated that their home lighting environment would satisfy them (with regard to luminance only). The majority of subjects (58.2%; n = 114) also voted against any kind of change in their current lighting situation. This assessment, however, was in strong contrast with the assessment of the interviewers, whose evaluation(s) indicated that there would be a need for better illumination in many households during daytime, especially in corridors (see Figure 2).

This contradiction between subjective assessment of persons in the target population and informed assessment of interviewees may be attributed to both the reservations many older people have about new lighting devices and technology in general, and the fact that many elders were not familiar with the important relationships between lighting conditions, wellbeing and health. The majority of the people interviewed were already utilizing technical devices on a day-to-day basis, but as commodities on a rather more or less superficial level, e.g., video recorders. Additionally, such devices were not seen as tools for assisting older individuals with remaining independent. This could be the reason why a majority of the subjects (75%; n = 147) could not imagine having technical support to preserve their independence, and/or to extend the period of independent living in their own households.

Methods

Research design

For testing the ALADIN prototype, a within-subject design was employed in which the following four conditions were implemented and compared: 1) baseline measurement (i.e., no system); 2) "advice and support system only" (AS); 3) "advice and support system plus lighting system with simulated annealing algorithm[iii] " (AL1); and 4) "advice and support system plus lighting system with genetic algorithm[iv] " (AL2).

Data were collected by means of questionnaires and physical performance tests that were conducted at five measurement points during the three months of testing at each household in order to compare the different settings, i.e., without any system (baseline and end testing), means with advices system only, AL1 and AL2, etc.

Instruments

Wellbeing: Wellbeing was assessed using the WHO-5 wellbeing index (18), with a scale ranging from 5 (all of the time) to 0 (at no time).

Quality of life: The "Skalen zur Erfassung der Lebensqualität" (SEL- "*Scales for assessing quality of life"*) was employed; this instrument includes questions on mood, health-related complaints, self-reported health, social environment, life attitude, body quality and life quality (19). Scales range from 1 (not at all) to 5 (very much), and

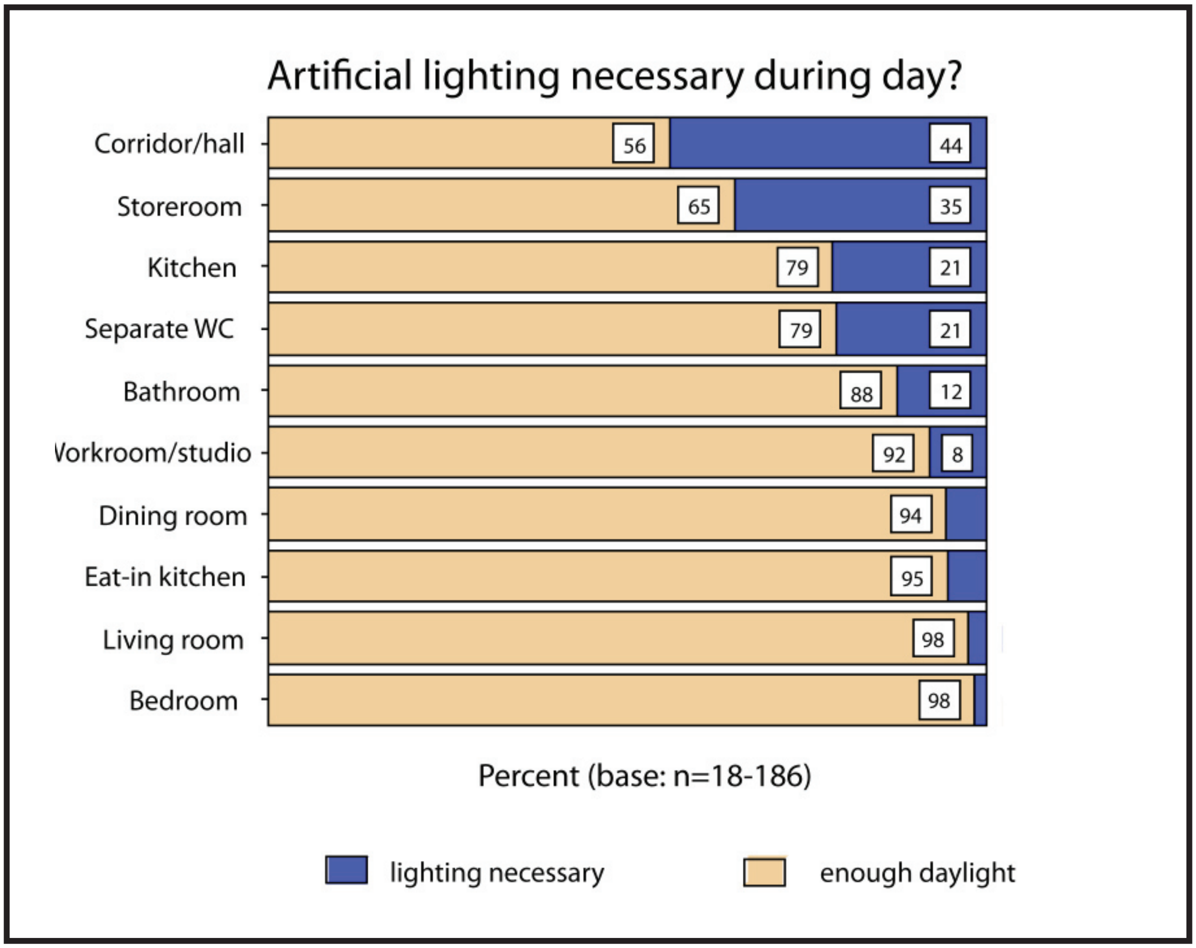

Figure 2: Lighting conditions assessed by interviewers (image source © Ulrich Becker, with permission).

sample items are, for example "Over the past few weeks I have felt tired and exhausted" or "Nowadays I see many things in a positive light".

Mental fitness: This was tested with the Image Recall Test (IRT)[v] and the Number Connection Test (NCT)[vi] from the Nuremberg Age Inventory (NAI) (20).

Physical fitness: To measure physical fitness, heart rate variability was used as a proxy for assessing psycho-physiologic self-regulation capacity.

Sleep quality: The Pittsburg Sleep Quality Index (PSQI) was used to assess quality of sleep (21). Questions refer to subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleeping disorders, intake of sleeping pills, and daytime sleepiness. Sample items include "How would you assess your overall sleep quality over the last four weeks" with a scale ranging from "very good" to "very bad"; and/or "How long did it usually take during the last four weeks until you fell asleep at night"; participants must respond by indicating the time in minutes spent during these events.

Usability and acceptance: One of the project partners (Apollis) developed a questionnaire to assess aspects of usability. Subjects respond on a scale ranging from 1 (almost never) to 4 (almost every day), and sample questions include: "How often during the last testing period have you been upset because of malfunction of the ALADIN system?" Questions also related to the user-friendliness of the ALADIN software (22). The questions about the user friendliness of the ALADIN software were based on the method of semantic differentials using two contradictive statements, such as "The software is complicated" vs. "The software is not complicated". A seven-point scale was used to indicate the degree of agreement to one of the two statements. Additionally, the AttrakDiff® question-

Table 1: Mean characteristics for baseline and final measurement (*Wilcoxon-Test for paired samples)

Characteristic	Range	Baseline Measurement		Final Measurement		*p* (dependent samples *t*-test)	*Cohen`s d*
		M	*SD*	*M*	*SD*		
WHO-5: Questionnaire on wellbeing	0 (low) – 5 (high)	15.00	6.00	10.50	3.42	< 0.01	0.92
SEL: Scales for Assessment of Life Quality		3.15	0.40	3.33	0.36	< 0.05	-0.47
IRT: Image Recall Test	0 (low) – 7 (high)	5.75	1.14	6.17	0.83	0.175	-0.42
NCT: Number Connection Test	Up to 300 s (low functioning)	26.72	9.61	19.50	6.49	< 0.001	0.88
PSQI: Pittsburgh Sleep Quality Index	0 (good sleep) – 25 (very bad sleep)	4.92	3.65	4.75	4.41	0.74	0.04
Fitness Test	high values indicate good fitness	0.025	0.03	0.017	0.01	0.75*	0.36

naire was employed, which measured perceived pleasantness and relative perceived goal-orientation of the device (23). The AttrakDiff® is based on 28 semantic differentials, such as “human vs. technical” and uses a seven-point scale to indicate the degree of agreement to one of the two adjectives presented.

Study participants and data collection

The sample for field-tests consisted of two men and ten women. Subjects were acquired through newspaper ads and word of mouth. They were offered a reimbursement fee of 1,000 € (approximately $1,400 USD). Subjects were only included in the study if they were at least 65 years old, living alone, and not suffering from any severe health problems (e.g., cancer or any psychiatric impairment).

Mean age of the twelve participants was 70.8 years (SD = 6.12). All participants were fully informed about the aims of the study, and provided active informed consent. All subjects voluntarily participated in the tests, with mandatory insurance arranged for every participant, and all participants completed the study. The field tests were approved by the ethics committee of the medical faculty of Ludwig-Maximilians-University, Munich. During field-tests participants were supported by technological supervisors who assisted whenever the participants indicated problems with the system. Supervisors were trained in handling the system for approximately two hours. Regular checks to assess outcome parameters were conducted by the supervisors and took place every three weeks. Supervisors were also trained on how to conduct the tests (questionnaires, tests on mental and physical fitness).

Results

Baseline measurements indicated that test persons were at a relatively high level of performance and wellbeing before beginning the field-tests. The mean scores and standard deviations for all parameters at baseline and final measurement are presented in Table 1, and report results of a Wilcoxon-Test for paired samples and effect sizes based on Cohen`s d.

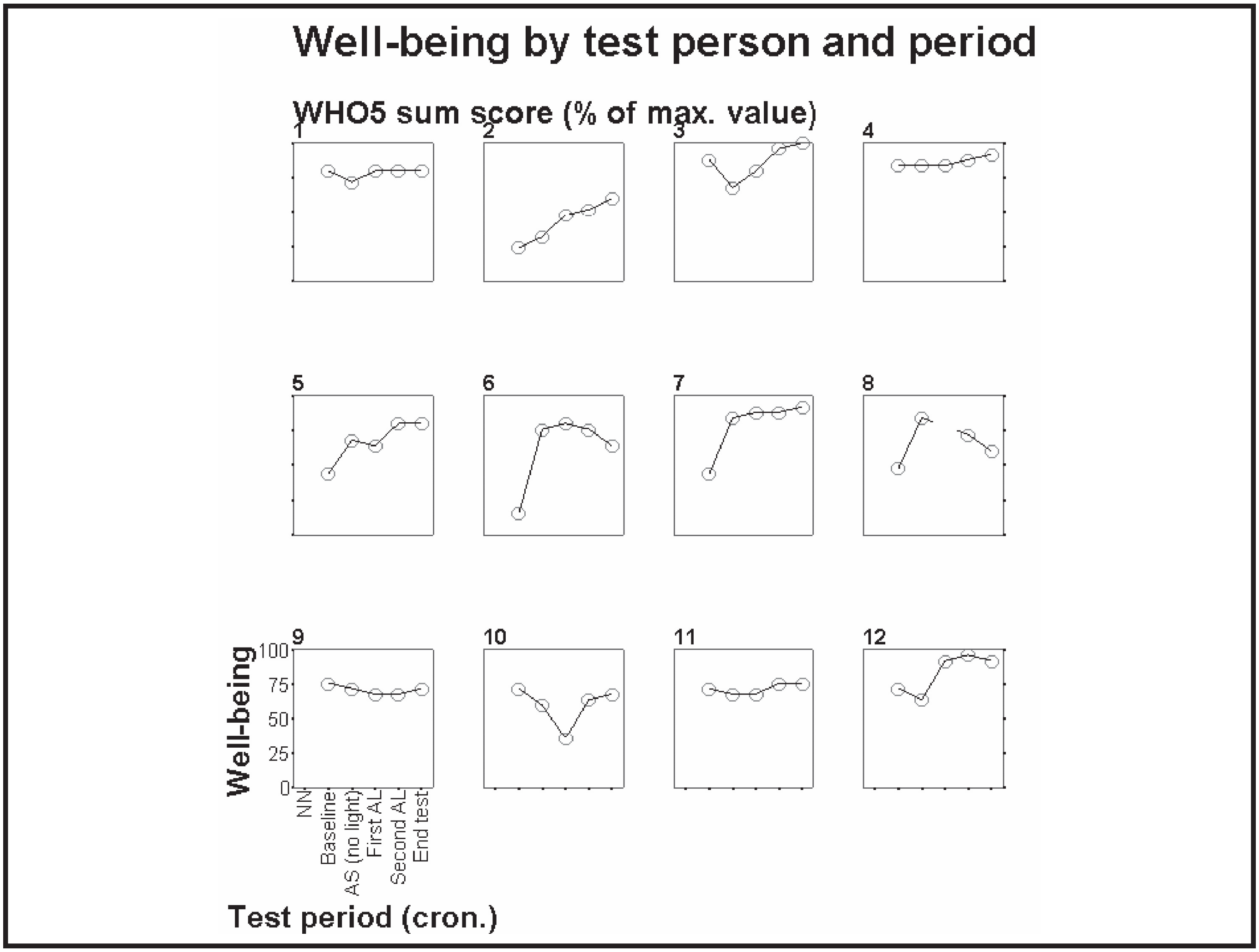

Figure 3: WHO-5-Index of wellbeing by test-person and period (Becker U, Kempter G, Maier E, Ritter W. Image source Apollis © European Union, with permission) [ii].

As can be seen in Table 1, statistically significant differences in effect size were found for wellbeing, quality of life, and mental fitness. In the following section, only the results that showed practical implications are discussed in detail. Additionally, usability results that might impact future system design will be discussed.

Wellbeing

Comparison of test scores of wellbeing measured with WHO-5 (18) show a significant increase over time (see Figure 2), from 60% in the baseline test up to 78% in the final test. This result also revealed high practical implications in terms of effect size measurement. Results of twelve participations are shown in Figure 3 and Figure 4.

Quality of life

A significant change in overall quality of life measured with SEL (19) was found between baseline measurement and the end point of the study. However, comparison of individual results seems to be quite diversified, and was not shown to be uniformly significant.

Mental fitness

During the period of the field-tests, subjects were asked to conduct mental training three times a day using the ALADIN system, mental training tasks consisted of standard cognitive performance tests suitable for elderly populations such as arithmetic problem solving, memory testing, and pattern recognition. Changes in mental fitness

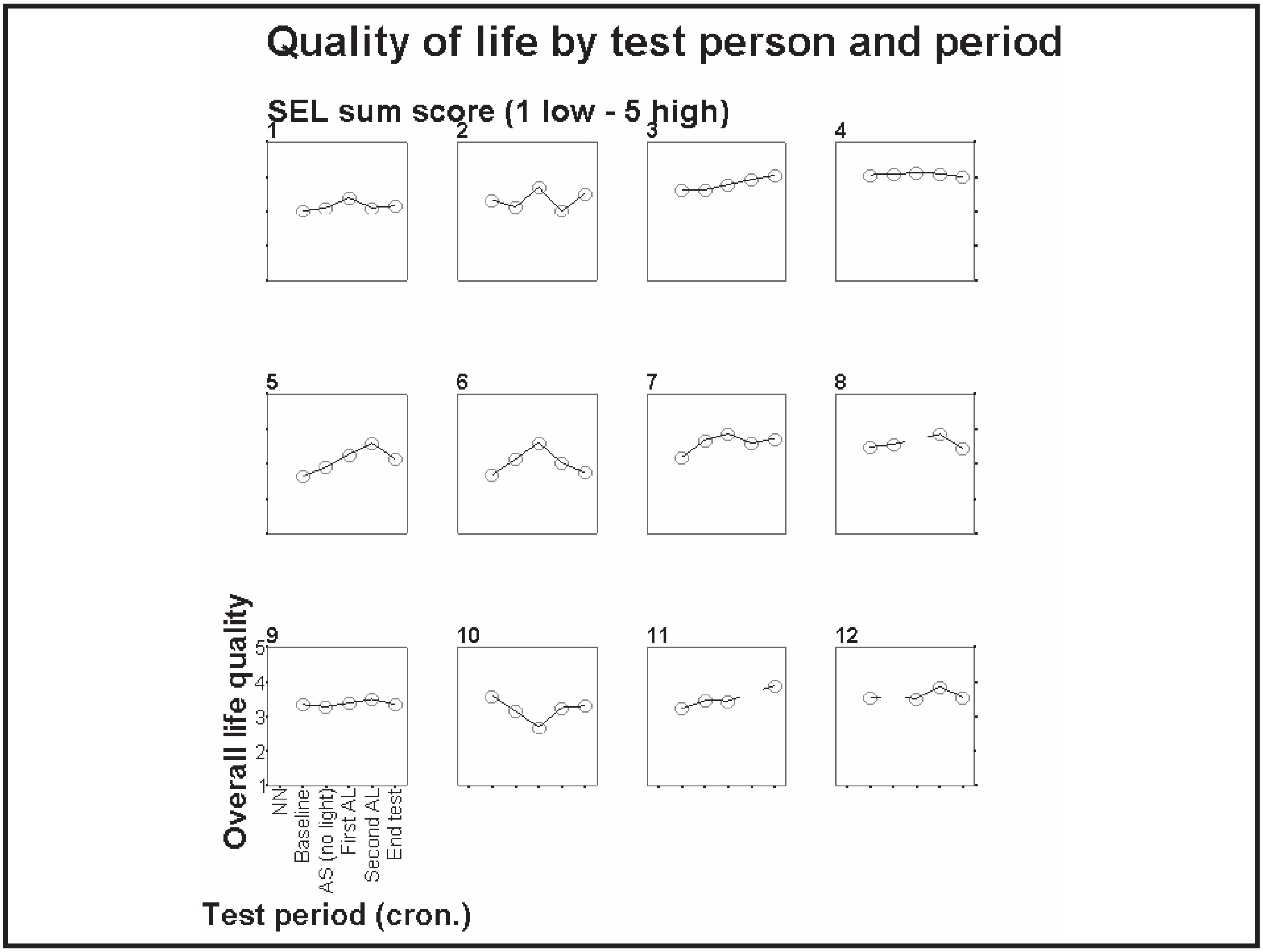

Figure 4: Quality of life (SEL) by test-person and period (Becker U, Kempter G, Maier E, Ritter W. Image source Apollis © European Union, with permission) [ii].

were measured with two tests from the NAI: the Number Connection Test (NCT) and Image Recall Test (IRT) (20). Significant changes between baseline measurement and end test measurement for the NCT were detected (see Figure 5). For the IRT there were no significant differences over time, as well as no significant changes detected in sleep quality and physical fitness.

Usability, acceptance and attractiveness of the system

Results indicated that the graphic feedback device (controlled via a standard TV set) and the programming module (remote control) were easy to handle, with a mean value of 2.6 (SD = 1.6) rated on a scale ranging from 1 (excellent) to 6 (extremely poor).

75% (n = 9) of participants assessed the graphical user interface of the ALADIN system as easy to use with an average rating of 1.9 (SD = 0.9) on a scale ranging from 1 (excellent) to 6 (extremely poor).

This positive assessment was corroborated by analysis of the ALADIN log files, which indicated distinct increase of ALADIN usage over time — not only for the lighting device, but also for the module containing the activation and relaxation exercises.

The usability and acceptance questionnaire also inquired about what subjects liked and disliked about the ALADIN system. Results indicated that the hardware components, i.e., the lighting devices, influenced the interior atmosphere in the households, even when it was not switched on (17).

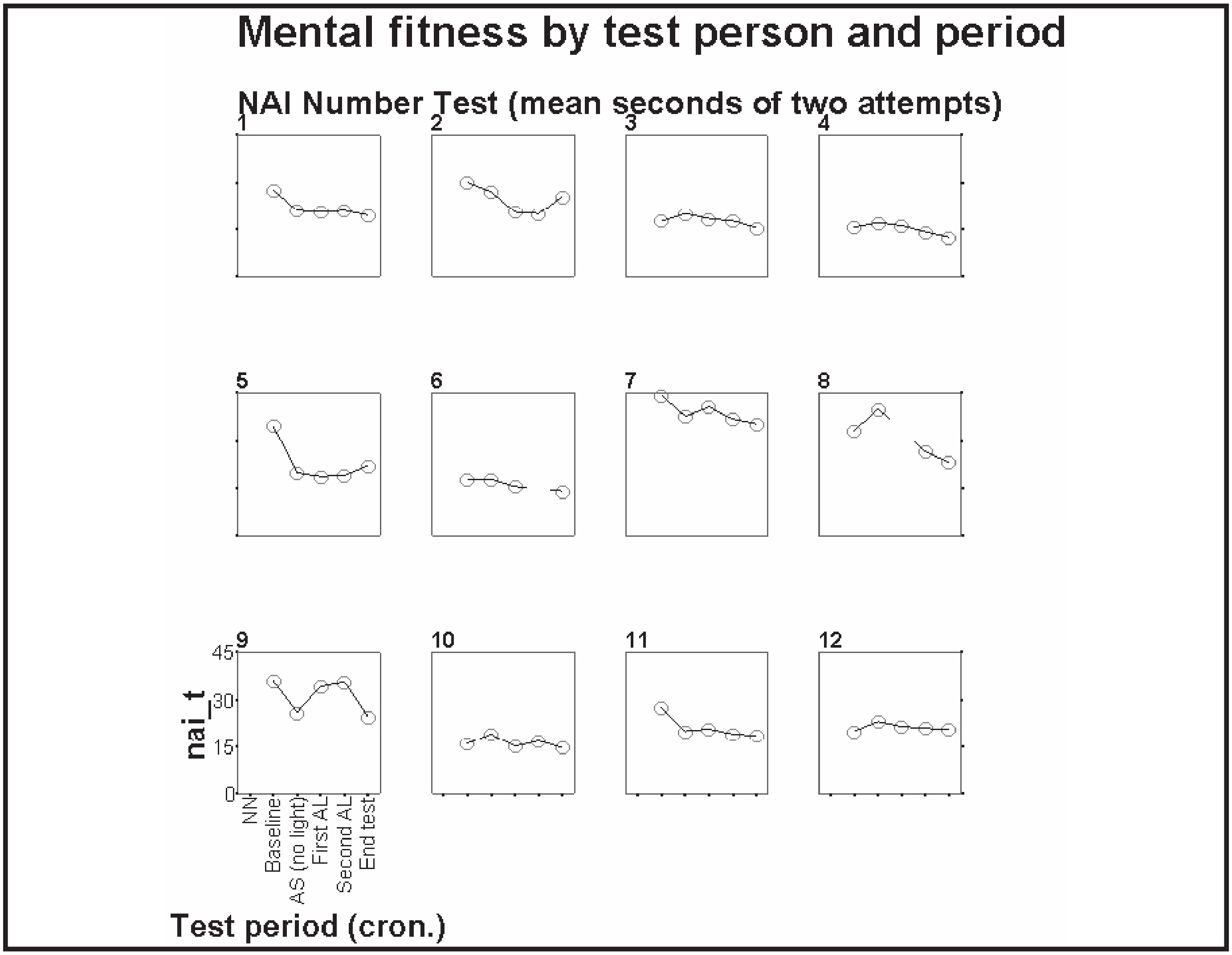

Figure 5: Mental fitness measured with Number Connection Test from NAI by test person and period (Becker U, Kempter G, Maier E, Ritter W. Image source Apollis © European Union, with permission) [ii].

This result was corroborated by focus groups that were conducted to investigate participants' experience with and acceptance of the ALADIN system. The need for an individual design of the lighting system was also mentioned in focus groups, with particular suggestion to allow the system to fit with the interior design of the respective room. The focus groups were conducted in order to gather more information about the subjects' experience with the ALADIN system, and were carried out in Aldrans at Bartenbach LichtLabor for the six test-persons from Austria and Italy, and in Bad Tölz for the six subjects from Germany. Only test-persons participated in the focus groups. Focus groups were questioned about their experience, what they would like to change, and what should not be changed about the system.

Discussion

In this report we provide the results of the ALADIN study that aimed to design and pilot-test a prototype technology for adjusting residential lighting conditions in accordance to psychophysiological conditions of elderly individuals. The initial demand-analysis conducted in Bolzano provided mixed findings: it clearly revealed that good lighting was seen as an important aspect for the target group. However, it also showed that elderly individuals have strong reservations with regard to implementing assistive technologies in their home environment. When gauging the obvious contrast between subjective and informed third-party assessment of the lighting conditions, it should be taken into account that test subjects did not report to have in-depth experience with modern technologies. Additionally, they were not familiar with the relationship between lighting conditions, health and wellbeing. Although reluctance to using technology in the homes as can be seen as fairly "typical" attitude for this age population, we posit that affinity toward using technology will likely change within the next generation(s). However, one must acknowledge that this anticipated change in technology acceptance cannot be considered as carte blanche for dismissing any reservations that future generations of elderly individuals may have. Nevertheless, the fast pace of technological development and the concurrently decreasing "half-life" of technological knowledge — should also be taken into account when predicting and assessing affinity toward harnessing the advantages of technology.

The results of field-tests indicated that there was a significant increase in perceived wellbeing and quality of life (which is a wider concept than wellbeing as it entails not only questions about mood, but also about health related topics and social support). The effect sizes found for these variables suggest that the test persons benefited from the field test or some of its components. Nevertheless, it is difficult to attribute that effect to a single factor. From the qualitative data generated in this study, and particularly from the data gathered in the focus groups, we infer that the social attendance; the feeling of participating in something important bestows the individual life with meaningfulness — and the continuous mental training through the activation exercises could be considered to be co-factors that indirectly trigger a significant increase in wellbeing. However, for some subjects the new light installation, and the hence improved light situation may predominantly be responsible for the effect. Ultimately, we infer that a central lesson learned is that the installation of the ALADIN system, in combination with social interactions, appeared to elicit positive impact on the wellbeing of the majority of test-persons (17). However, it should be noted that power analysis revealed that the present study lacked power, and only had a 20% probability to depict a treatment difference at a two-tailed 0.05 significance level. Therefore, additional effects are likely undefined due to the small sample size of this pilot study. Furthermore, the power analysis revealed that at least 65 subjects should be included in a crossover design in order to have an 80% probability of elucidating treatment differences at a two-tailed 0.05 significance level. Nevertheless, we opine that the lack of power of our study is common for pilot-studies like this field-test. The initial results reflect tendencies for effect, and thus we hold that additional studies should be conducted with larger population samples.

In sum, the effectiveness of assistive technological systems as stand-alone approaches to augmenting wellbeing and quality of life in elders is questioned by our results. It may well be that without any social embeddedness, the devices might have not been proven to be effective. However, one should always bear in mind that meaningful interpersonal relationships in real life might turn out to be the most important factor for wellbeing and health of human beings. Furthermore, social connection appears to be indispensable for wellbeing (24). Nevertheless, as we have shown in this study, technological solutions such as the ALADIN system are able to not only accommodate, but actually improve these important aspects of wellbeing and health if they are seen and used not merely as technological devices but actually as socially embedded technologies (25). For the future development of technologies, we argue that how, and in what ways, technology can facilitate biopsychosocial function should explicitly be emphasized in order to gain optimal results. It is worthy to devote future studies to assess, if effects may be attributed to enhanced social interaction alone. Nevertheless, bearing the well-known placebo effect in mind, it should be recalled that an intervention of any kind naturally must consist of two complementary components: an agent, i.e., an intervention or pseudo-intervention, and a vehicle that carries the respective agents/intervention (26, 27). Transferring this insight from placebo research to the field of AAL technologies, we opine that focus should be placed upon both the technological aspects, and to their ability to facilitate social engagement. This approach speaks strongly in favor of a whole-systems approach that not only embraces external environmental factors (e.g., environmental, architectonic and technological domains) but also internal environmental factors that strengthen the individual resilience (e.g., sense of coherence, social support and spirituality) (28-30).

There were also practical problems associated with the user-friendliness of ALADIN. We pose that to ensure user acceptance of AAT it will be important to develop software and hardware components in close cooperation with the target group in a participative and iterative process. Specifically, the lighting installation must either be designed as a "camouflaged" supplement to the existing infrastructure, or correspond to individual aesthetic preferences. By integrating elderly persons at all stages of the development process, acceptance problems can be avoided and ease/value of use may be facilitated.

Limitations of the study

Due to time and financial constraints, this study was limited in several ways. First, the three parts of the field trials were conducted in different seasons of the year, i.e., winter time, spring and summer. This may have caused seasonal influences upon results, i.e., less impact of artificial lighting in spring and summer. Therefore, we suggest testing the system especially during wintertime when natural lighting is at a minimum and artificial lighting may have an increased impact on wellbeing, sleep quality and alertness. The design of the present study did not permit correction of this potential confound. Second, due to the within-subject design, the time for testing the different parts of the system was too short to be able to detect changes in certain parameters (e.g., sleep quality and physical fitness). Hence, we suggest that any future studies should use a between-subject design comparing four groups, i.e., advice system only, lighting system only, advice system and adaptive lighting as one system, and a control group. This would additionally allow comparison of the different parts of the system. Third, the sample (12 participants) was very small, resulting in low statistical power of the study, as indicated above. Therefore, we propose that future studies should recruit a larger number of participants to be able to more accurately and specifically detect effects of new technologies. As well, it should be taken into account that the present study did not control for the frequency of the visits of the technical supervisors.

Conclusions

The results of this study indicate that we are still in an early stage of both developing new technological devices, and understanding their impact on lifestyle and independence. We cannot attribute the positive results of our field tests of wellbeing and quality of life solely to technological factors. Rather, we suppose that the increased social contact and attention has an additive effect (25). Additionally, it is important to remember that new technologies can be used to reduce burdens on all individuals, not only the disabled and/or aged. However, when designing technological devices for older individuals, and particularly for the fragile elderly, it is vital to take both their special needs and demands (concerning usability and design) as well as their potential reservations to the use of technology or amenability to change in general into account. While we consider usability and design as important parameters that may impact acceptance, we reiterate a word of caution here: the potential of AAT's for improving the lives of the elderly can be exploited to a greater degree by embedding them into social settings that facilitate social contacts. This in turn may heighten the effects and increase acceptance. However, in order to be both accepted and effective, AAL technologies should both be adequately designed and socially enabling.

A final question remains whether a "cloud of care"[vii] (31) that centers upon social dimensions might have greater impact on fostering independence than a cloud of care that is focused upon assisting technologies. This and other questions, however, must be addressed in order to justify the research and developments in the field of AAL. Our group is dedicated to these pursuits.

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Disclaimer

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Competing interests

The authors declare that they have no competing interests.

Notes

i. More detailed information about the ALADIN prototype will be made available by the first author upon request.

ii. Figure from Ambient Lighting Assistance for an Ageing Population" (ALADIN) Report on the test results and the evaluation of the system as a whole. Responsible Partner: APOLLIS. 2009 Jan 7.

iii. Simulated annealing algorithm: the ALADIN prototype aims at varying the lighting parameters of an individual in order to achieve a certain psycho-physiological state, characterized by the extracted features. For example, studies show that the more relaxed a person feels, the lower their skin conductance response (SCR), skin conductance level (SCL) and heart rate (HR) features are. Thus, the system's goal is to try and find the minimum of the SCR, SCL and HR features in the lighting parameters domain to achieve the subject's relaxation or activation, respectively. Achieving a person's desired psycho-physiological state is a problem of identifying the specific lighting parameters that determine the optimum of biological features. Such a problem can be solved using stochastic algorithms. A study of three different algorithms showed that a procedure called "simulated annealing algorithm", yields good results for our particular problem.

iv. Genetic algorithms are inspired by evolution in nature. Thus, a basic assumption starts from a given population of individuals. The idea is that finally the strongest individual (i.e., most fittest for the purpose at hand) will survive. In the ALADIN application individuals stand for a specific light-set and light-distribution in the room. Their fitness-value is then determined by measuring psycho-physiological responses to the light-set resembled by the individual in accordance to desired results (target values). In short, during the adaptive lighting session, the most appropriate light-setting, of course in accordance with an individual's current state and dependent of the desired target result (activation or relaxation) will be indentified. Further information is available by the authors upon request.

v. IRT = Image Recall Test; subjects are presented seven pictures in total each for approx. three seconds. Directly after this people are asked to repeat what they have seen.

vi. NCT = Number Connection Test; measures the time a person needs to draw a line between numbers in ascending order.

vii. "cloud of care" means many different systems that support and help people in the management of everyday activities in their homes, including medical services.

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