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Effects of Ambient Lighting Displays on Peripheral Activity Awareness

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ABSTRACT The emergence of ubiquitous sensing and the Internet of Things (IoT) have inspired the development of ''smart'' everyday objects, which offer tremendous opportunities for maintaining the quality of life in ambient assisted living (AAL) environments. Inspired by the future possibilities of connected everyday devices, we envision a peripheral activity-based awareness system that captures human activity information and renders this information to enhance context awareness and support social connectedness between the elderly and their caregivers. Leveraging ambient intelligence and IoT technologies, ambient displays can convey activity information in the periphery of our attention. In particular, light has been used as a means to display ambient information and there is scientific evidence that it can enhance well-being, interconnectedness, and improve productivity. In this paper, we undertake two studies, first through an exploratory study we investigate the features of light suitable for conveying subtle activity information within the periphery of the users' attention for promoting context awareness. Also, we examine the preferences, perceptions, and interpretations of ambient lighting configurations of prospective caregiver's for conveying the activity information of older adults. In a second study, we assess the implications of activity awareness through lighting on cognitive performance, moods, and social connectedness. The set-up and design decisions of the second study were partly informed by previous research and by the outcomes of the first experiment. Together, these studies provide additional design guidelines for representing activity information with ambient lighting and highlight potential benefits and usage possibilities for lighting displays within the AAL domain. Furthermore, the results indicate a significant effect of activity awareness on cognitive performance. However, there were no significant effects of activity awareness through lighting on moods and social connectedness. Finally, we discuss the design guidelines and implications of these findings for designing activity-based ambient lighting displays for AAL environments.

INDEX TERMS Ambient intelligence, ambient displays, ambient lighting, ambient assisted living, perception, context awareness, social connectedness.

I. INTRODUCTION

It has been shown that ambient intelligent solutions can have positive implications on improving the health and well-being of older adults [1]. A widely accepted definition of ambient intelligence (AmI), was drafted in 2001 by the ISTAG [2], an EU advisory group, to demonstrate a novel approach to designing intelligent environments with a human-centered focus on enhancing the quality of life. An excerpt from the ISTAG mantra [2], describes an AmI world where, ''People are surrounded by intelligent intuitive interfaces that are embedded in all kinds of objects and an environment that is capable of recognising and responding to the presence of different individuals in a seamless, unobtrusive and often invisible way.'' Ambient assisted living (AAL), a sub-domain of AmI, seeks to design technological solutions to facilitate independent living and improve the quality of life of the elderly while helping to reduce government spending on elderly health care. Within AAL, human activity recognition (HAR) is of paramount importance as it provides a means to monitor activities of daily living (ADL) and to support independent living of the elderly. In essence, HAR exploits sensors and advanced algorithms to automatically detect human activities [3].

As we experience a new wave of AAL technologies, privacy and protection of personal information remain as considerable challenges of continuous surveillance tools [1], [4].

Explicit renditions of human activities for instance, ''walking'', ''sleeping'', ''cooking'', ''toileting'', and ''bathing'' among others often result in privacy concerns regarding personal information. Pedersen and Sokoler in [5], suggested a ''kind of shielding'' of personal activity information through abstraction, utilizing features such as visual or auditory cues to enable ''non-attentional demanding awareness''.

Peripheral awareness is exemplified by, ''our ability to maintain and constantly update a sense of our social and physical context'' [5]. Ambient information systems, a paradigm of ambient intelligence, is rooted on the premise of peripheral awareness, where information is subtly portrayed in the periphery of one's attention [6]. Thus, users can perform their primary tasks in the foreground while simultaneously receiving context information in the background of their attention.

In a digital era, people often experience ''information overload'', from emails to an assortment of social media applications [7]. Ambient displays can remarkably reduce the amount of information mentally processed by providing an overview of the content. Moreover, ambient displays [8], exploit the notion of calm technology [9], through the effortless transition from the foreground to the background of the user's attention. Therefore, a crucial feature of ambient displays is their capacity to be perceived at a quick glance, which triggers pre-attentive processing to reduce the user's cognitive load. Consequently, ambient displays present enormous potential in AAL environments, as they unobtrusively facilitate information access to support context awareness and improve interpersonal relationships as demonstrated in [10].

Essentially, when designing ambient lighting displays the designer has to establish a context for decoding the information [11]. Primarily, in order to understand the information received, the viewer has to understand the significance of each lighting characteristic. In certain instances, users may understand intuitively or can be explicitly told about the significance of the encoding [7], [11]. Occasionally, there are discrepancies between the designer's intention of the encoding and the viewers interpretation of the encoding. In reality, what really matters is what is understood by the viewer and not the designer's intention [11].

Human consciousness i.e. an individual's state of awareness in response to a stimulus [12] is an intriguing topic, which has gained much attention in human computer interaction research to explore how this phenomenon affects changes in behaviour [13]. More specifically, human cognition, an important aspect of human consciousness is concerned with a number of mental processes such as perception, attention, memory, reasoning, problem-solving and decision making [14], some of which will be explored in this work.

This paper is an extension of the contribution in [15], which was presented at the BODYNETS 2016 conference in Turin, Italy. In this work, we build on the proposal in [4], [16], and [17] to present activity information using subtle ambient lighting displays to enhance context awareness and support social connectedness between the elderly and their caregivers. Following this proposal, a smartphone activity recognition system was developed exploiting a hybrid Support Vector Machine and Hidden Markov Model (SVM-HMM) model, with an overall accuracy of 99.7% [18], to classify six basic activity states namely, walking, walking upstairs, walking downstairs, standing, laying and sitting. To provide abstraction and privacy protection, the explicitness of the basic activity states was reduced to activity levels [19] i.e. ''resting'', ''passive'' and ''active''. This abstraction of activity states into activity levels was contingent on user generated mappings where users mapped activity states to levels, based on their individual jobs and perspectives of which activity states they considered to be active, passive or resting.

In this paper, we describe two experiments to augment the work discussed in [15]. In the first study, we explore how ambient lighting parameters can be exploited to encode activity information. Here, we examine prospective caregiver's preferences, perceptions, and interpretations of three ambient lighting configurations for conveying the activity information of older adults. By this, we provide consistent user-centered design guidelines for encoding activity information within an AAL context. In a second experiment, we assess the implicit and psychological effects of peripheral activity awareness through lighting on cognitive performance, moods and social connectedness in short time periods guided by the design guidelines in the first experiment.

Our findings provide additional design guidelines for representing activity information with light and highlight potential benefits and usage possibilities for ambient lighting activity displays within AAL domains. Also, the results demonstrate a significant effect of peripheral activity awareness on cognitive performance in problem-solving tasks. However, there were no significant effects of peripheral activity awareness through lighting on implicit memory, moods and social connectedness. Consequently, the implications of these findings for designing activity-based ambient lighting displays for AAL environments are also discussed.

The rest of the paper is organized as follows. Section II describes state-of-the-art on ambient lighting displays and reviews the psychological and physiological processes involved in light perception. In section III, we provide an overview of the experiments conducted and describe our research goals. Subsequently, in sections IV and V, we discuss the process of evaluation and expound upon our findings. Finally, we make our concluding remarks and discuss our limitations and future work in section VI.

II. RELATED WORK

A. AMBIENT LIGHTING DISPLAYS

In an AAL setting, the integration of sensors, the Internet and lighting can realize systems that go beyond illumination. In particular, ''smart'' connected lighting systems are capable of sensing and communicating vast amounts of information about the environment. Thus, light has huge potential for enabling context awareness and enhancing well-being. Also, the varying visual properties of light e.g., colour, brightness, saturation, position and frequency of changes [4], [7] make it ideal for encoding and sharing physical activity information.

Within AAL, the rendering of activity information through ambient displays has demonstrated solid potential for strengthening connectedness between the elderly and their caregivers [10], [19]. For instance, the SnowGlobe, an ambient lighting display was used to encode movement information in an AAL context, for creating interpersonal awareness between two remote persons. In this design, movement information was rendered using a measure of purple light and fluttering snowflakes. When communication was initiated by one person, the other person's snowglobe reflected a bright orange light accompanied by fluttering snowflakes. Similarly, the Casablanca Intentional Presence Lamp [20], conveyed presence information to two remote users using different images and colour. In another scenario, the Lumitouch [21] deployed ambient light for emotional communication. However, in these studies, various types of information (e.g., presence and emotion) were encoded together with or without physical activity information and as such they lack in a consistent framework for encoding activity information especially for AAL domains.

Previous studies have exploited lighting features for conveying physical activity information using different encodings. For instance, ActivMON is a wrist-based ambient display, which uses coloured lighting to inform users about their activity levels [22]. In addition, a pulsing light is used to convey information about the activity levels of others. ActivMON uses a colour fade from red-to-green, where red shows no daily activity while green demonstrates that the user's daily activity goal is achieved. A fast pulsing light indicates high physical activity levels for other users while a slow pulsing light shows their inactivity. The HealthBar [23] is an ambient lighting display, deployed in working environments to counteract the effects of prolonged sitting. The HealthBar exploits a light tube placed at the user's desk, which fades from green-to-red. A fully charged HealthBar is initially set to green and gradually fades to red to prompt the user to take a break. If the break is not initiated, a pulsing light is used as a break reminder. In a similar way, ambient light was deployed through the Movelamp [24] to stimulate increased movement in office environments. Using a Philips Living Colours lamp, the Movelamp was positioned in the user's peripheral vision. It changed using a colour fade from green-to-red with increasing brightness. Green shows periods of physical activity while red displays no activity, the brightness was a medium to alert the user's attention [24]. The Pediluma ambient display, is a shoe accessory that uses one colour (green), with varying intensities to visualize the wearer's physical activity [25]. More physical activity is reflected with a brighter glow, encouraging users to increase their activity levels.

Overall, we observed that colour, brightness, position and a pulsing light are the four most common lighting features for encoding activity information. However, within an AAL context, a pulsing light would be more relevant to convey an emergency or crisis situation, which is not an intended goal of this research. As an aside, most of the earlier studies on ambient light displays, encoding activity information, have focussed primarily on how the receipt of information influenced the reciever's activity states and levels. Quantitative evidence showing how people perceive the visual information received is largely left unexplored. As mentioned earlier, ambient displays are meant to trigger pre-attentive processing, an intuitive process often based on instinct, snap judgements and gut feelings as mentioned in [26]. As Gladwell argues, rapid cognition is not always correct [26], which in this case, can be harmful within an AAL setting. Consequently, opening up the problem space for researchers to explore whether the caregiver's perception of activity encodings at a glance, matches with the physical reality of the elder's activities.

B. DESIGN GUIDELINES FOR AMBIENT LIGHTING DISPLAYS

A considerable amount of work has been published on design guidelines for the design [6], [27], [28] and assessment of ambient displays [8], [29]. For example, Pousman and Stasko [6] analyzed a wide array of ambient displays and derived a taxonomy based on four dimensions: 1) *Information capacity:* "the number of discrete information sources that a system can represent." 2) *Notification Level:* "the degree to which system alerts are meant to interrupt the user." 3) *Representational Fidelity:* "describes a system's display components and how the data from the world is encoded into patterns, pictures, words, or sounds." 4) *Aesthetic Emphasis:* "the relative importance of the aesthetics of the display." Additional design dimensions were discussed by Tomitsch et al. [28]. Also, Mankoff *et al.* [8] suggested a number of heuristics for evaluating ambient displays. These design guidelines and heuristics were used to set the initial requirements for our ambient lighting display. However, they were still too general and more specificity would better assist designers to tailor ambient lighting solutions to encode physical activity information. In an attempt to fill this gap, Matviienko et al. [30] derived a set of guidelines for encoding lighting parameters. Yet, these guidelines were not matching the intended outcome of our overall research i.e. not only to provide context awareness but also to enhance the social connectedness experience through the use of lighting parameters such as colour.

Therefore, the specific colour choice should not only convey activity information but also evoke a subtle sense of remote presence based on the elder's current activity level. In retrospect, the derived lighting patterns for presenting situations in [30], were not sufficient for both end-goals as the authors recommended different colours for status information classes showing presence and physical activity data. Consequently, driving the need for a colour scheme that could achieve both outcomes.

To fill this gap, we reviewed the literature on colour symbolism. Our findings showed varied interpretations on colour, which were heavily reliant on culture, age and situational context. For example, Ou *et al.* [31] demonstrated affective implications of lighting colour using colour emotion scales such as ''passive'' or ''active''. The more reddish the colour, yielded a more ''active'' colour emotion response by both elderly and younger adults while higher variations of blue were in most instances ranked as more passive by both user groups. Moreover, as demonstrated in [19], red was useful for showing high activity levels while simultaneously evoking an invigorating sense of presence, while blue was convenient for showing periods of low activity levels with a lesser degree of remote presence. These findings helped to set the stage for the design choice on the colour scheme.

C. PSYCHOPHYSICAL EFFECTS OF LIGHT

Many researchers have accrued evidence that light can affect well-being [32], interpersonal communication [33], social functioning [34], improve performance on a variety of cognitive task and interpersonal behaviour [35], time estimation [36] and create an inviting and pleasant atmosphere [37]. Whereas other scientists have failed to identify significant influences of light on moods [35], [38] and a variety of cognitive tasks [39], [40].

Added to the behavioural effects, light has been shown to affect various psychophysiological aspects such as, alertness, arousal level, heart-rate, body temperature and circadian rhythm [41], [42]. Moreover, behavioural lighting research documents positive influences of light and colour on moods [43].

Primarily, the meaning of colour is based on experience, coupled with physiological responses [44]. For example, Jacobs and Hustmeyer deduced from physiological measurements such as galvanic skin response, heart and respiration rates, that red is remarkably more arousing than either blue and yellow, while green induces greater arousal levels than blue [45]. Moreover, the meaning of the colour can influence arousal levels. Another case in point is illustrated by Gerard, who while using psychophysiological measures reported that the higher arousal levels associated with red is triggered by unpleasant associations of red with blood, injuries, fire, aggression and danger whereas the low arousal levels associated with blue is induced by the association of blue with serenity, the skies and friendliness [46]. Conflicting impacts of the colour red on psychological behaviour is demonstrated in [47] where red is associated with happiness and excitement.

Altogether, a general inference can be drawn on the potential influence of light, especially coloured light on interpersonal relationships, mood and performance on various cognitive tasks. Still a deeper understanding of the implications of coloured lighting is needed to facilitate the design of ambient intelligent lighting solutions relevant for an AAL context [48]. Based on these considerations, we designed an experiment to explore suitable ambient lighting configurations for encoding human activity information and also to investigate the effect of activity-based ambient light on cognitive tasks and moods.

III. EXPLORING ACTIVITY-BASED AMBIENT LIGHTING CONFIGURATIONS AND THEIR EFFECTS ON COGNITION AND MOODS

To find more appropriate guidelines for encoding activity information to fit an AAL context, we designed two studies. Primarily, we focused on understanding how potential caregivers perceived and decoded lighting cues and examined their preferences for lighting parameters for encoding the elderly's physical activity information to provide context awareness and elicit feelings of social connectedness. A review of published work and a user-centered approach were adopted to design three lighting configurations. Specifically, we illustrate the design and evaluation of three lighting configurations taking into consideration the following: (i) position of the light source, (ii) frequency of light changes and (iii) lighting colour properties (hue and brightness).

Inspired by the work in [30], we designed a study where participants had to identify light changes and state their preferences for the lighting configurations. Matviienko et al. designed a study where participants had to map lighting patterns to a set of scenarios. However, our study was centered around an AAL context with the goal of finding the best lighting parameters for encoding the elderly's activity information in order to provide context awareness to the caregivers. Based on the aforementioned requirements we evaluated:

- noticeability and accuracy of interpretations of the lighting configurations. We assume that an ambient light that provides clear information and is perceivable at a glance would be less distracting and easily move from the foreground to the background of attention.
- subjective attributes such as usefulness, suitability, intuitiveness, etc., towards the system. We hypothesize that the higher the subjective positive attitudes toward the ambient lighting configuration, the more the likely it will be adopted.
- user's perceptions on future system adoption and their recommendations for lighting parameters to encode activity information.

As discussed in the related work, numerous experiments have shown that the properties of light can positively improve performance in cognitive tasks and improve moods. Moreover, Fitzsimons and Bargh posited that the psychological presence of relational contacts can trigger interpersonal goals, which are pursued unconsciously [49]. On that account, we sought to understand the effects of the awareness factor (in this case, the elderly counterpart's activities) that brings about the change in the selected lighting configuration. In essence, the primary objective of study two, was to investigate the effects of activity awareness through an activity-based ambient lighting display on cognition and moods. To support this evaluation, an intervention and a control condition were designed, whereby the awareness of activities was the only independent variable. We assume the following:

- the implicit perception of activity states through ambient lighting can positively affect moods and improve cognitive performance in implicit memory and problem-solving tasks.
- participants who are made aware that the lighting display renders their elderly loved one's activities would be more positively impacted than those who were not.

IV. STUDY ONE

The purpose of study one was to understand how potential caregivers perceived and decoded lighting cues and examined their preferences for lighting parameters for encoding the elderly's physical activity information to provide context awareness and elicit feelings of social connectedness. In this section, we describe the detailed procedures of our design and evaluation. In addition, the research outcomes are also discussed.

A. PARTICIPANTS

Fourteen (14) participants were recruited from the University of Genova to take part in the experiment, which lasted 50 minutes per participant. The demographics of the participants is summarized in Table 1. The sample was predominantly male with only two female participants. Also, the sample was dominated by Italians (5 males and 1 female), followed by Pakistanis (3 males), with a few others including Tunisian, Colombian, Iranian, Indian and Lebanese males.

TABLE 1. Table showing participants' descriptive data.

Characteristics	No. of Participants	Percentage (%)
Gender		
Male	12	85.7
Female	2	14.3
Age		
18-24	3	21.4
25-34	9	64.3
35-44	2	14.3
Marital Status		
Single	9	64.3
Married	5	35.7
Nationality		
Italy	6	42.9
Pakistan	3	21.4
Colombia	1	7.14
India	1	7.14
Iran	1	7.14
Tunisia	1	7.14
Lebanon	1	7.14
Occupation		
Employed	4	28.6
Unemployed	8	57.1
Unknown	2	14.3

All participants had normal or corrected-to-normal visual acuity and were tested for colour vision deficits using the Ishihara colour blindness test [50]. Participants were informed of the required procedure and signed their consent form.

B. DESIGN

The primary goal of this experiment was to empirically assess the users' perspectives regarding the use of lighting parameters to convey activity information of an elderly person to a caregiver in order to support context awareness and promote social connectedness. Accordingly, the lighting parameters deployed must be perceived at a glance, non-distracting and aesthetically pleasing in order to evoke a subtle sense of presence. Based on existing literature and a cognitive walk-through with six prospective users to inspect their interpretations of lighting parameters (position, rate of change and colour properties) on encoded activity information, we had four main findings:

- Ambient light must be perceived at a glance, easily controlled (e.g., turned on or off, adjust the brightness levels etc.,) and should be positioned within the field of view of the users. As mentioned in [4], lighting applications should be easily incorporated in users' everyday routines. One recommendation of a light source that would readily fit this criterion, was a desk lamp.
- A pulsing light might be too distracting and fails to inconspicuously convey activity information.
- The most obvious properties of light (hue and brightness) should be varied smoothly to subtly convey activity information.
- Red was most favoured to represent a high activity level, green for an intermediate level and blue for resting.

As discussed earlier, a user can at any point in time be in one of three activity levels: active, passive or resting. Each activity level can be represented by one distinct lighting colour property. Also, the amount of time a user stays in an activity level is another dimension that can be overtly relayed (represented by lighting colour property) or covertly relayed (intuitively discerned by users). Based on these findings, three lighting configurations (COL_BRI, BRI_ONLY, COL_ONLY) were designed.

Configuration COL_BRI can convey the activity level and also the temporal duration of stay in a particular level. Figure 1, shows configuration COL_BRI, where red, green and blue lights represent active, passive and resting levels respectively, while changes in light intensity depict how long a person has stayed in a specific activity level. From [18] and [19], our human activity detection model can detect a user's activity level every 1.28 seconds. Consequently, the minimum amount of time for the ambient lighting colour change is 1.28 seconds. For this experiment, the brightness for an activity level was initially set to 33.3%, while activity levels lasting for more than 10 seconds and 20 seconds were set to 66.6% and 100% respectively.

Inspired by the Pediluma [25], configuration BRI_ONLY exploited changes in brightness of a single default green colour to convey the change in physical activity levels. Temporal duration of activity levels was not overtly conveyed. Configuration BRI_ONLY is depicted in Figure 2.

FIGURE 1. Lighting configuration COL_BRI adapted from [15].

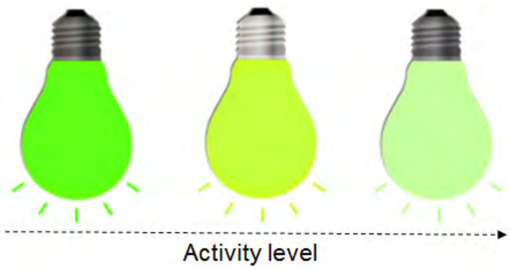

FIGURE 2. Lighting configuration BRI_ONLY adapted from [15].

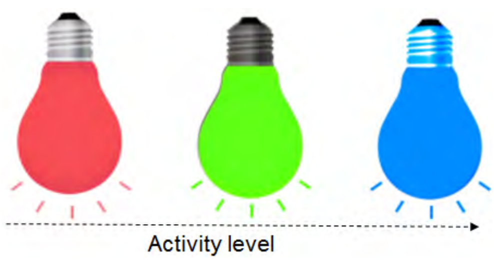

FIGURE 3. Lighting configuration COL_ONLY adapted from [15].

To convey changes in activity levels, configuration COL_ONLY employed changes in lighting colour in the same manner as configuration COL_BRI. Like configuration BRI_ONLY, the temporal duration of activity levels was not overtly represented. Figure 3, demonstrates lighting configuration COL_ONLY.

C. EXPERIMENT SET-UP

The experiment was carried out in a room, located at the University of Genova, with dimensions of 10.4 x 4.3 meters. The walls and ceiling were off-white and the floor consisted of marble tiles. The ambient light source was a desk lamp exploiting the Philips Hue, a connected lighting system that enables lighting colour properties to be controlled over a network. The Philips Hue is furnished with a network bridge for connecting to the internet and provides an API for building custom applications to control the light over a network.[1] The system was operated 15 minutes before the experiment to stabilize the illumination level and also the internet connection. A hand held tally counter was used by participants to monitor the changes in lighting colour. The experiment was divided into two phases using a repeated measures design methodology. Figure 4, illustrates an example of a participant performing the experiment.

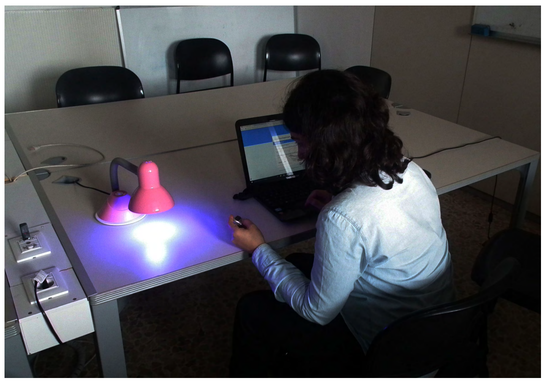

FIGURE 4. An example of a participant performing experiment adapted from [15].

D. PROCEDURE

Phase one investigated how quickly participants processed the ambient information at a glance and examined the accuracy of recognition of the lighting changes. Notably, in this phase, participants were told that activity information was encoded through different lighting patterns without specifying the details of the mappings. A set of five practice trials were deployed to allow participants to familiarize themselves with the protocol and to clarify their misconceptions. Subsequently, they were given a total of three block trials with a randomized presentation of lighting configurations COL_BRI, BRI_ONLY and COL_ONLY with each block comprising of ten trials. The unified length of each trial was 30 seconds with each activity lasting a minimum of 1.28 seconds (i.e. the minimum detectable activity duration of the hybrid SVM-HMM HAR model). Participants were instructed to click the counter each time they noticed a change in light. Following the display of each lighting pattern, the participant had 30 seconds to respond to the questions concerning each trial. With respect to the accuracy of change noticeability, participants were to refer to the counter and respond how many times they noticed changes in the light. The total change count was the final number seen on the hand-held tally counter. Participants then selected the correct description of the presented configuration from a list of options. Additionally, participants were asked

[1] https://www.developers.meethue.com/documentation/how-hue-works

to report the summation of the number of distinct lighting configurations observed and describe their interpretations of what each configuration tried to convey.

In phase two, the significance of the lighting parameters and their mappings to activity levels (passive, active, resting) for each lighting configuration was explained. Subsequently, an activities of daily living (ADL) scenario of an elderly person was described to each participant, then he or she viewed the simulated activity information for lighting configurations COL_BRI, BRI_ONLY and COL_ONLY in a randomized order. After viewing each lighting configuration, participants performed a heuristic evaluation in terms of ten desirable features (usefulness, suitable abstraction, suitability, interest, perceptibility and distinctiveness, noticeability, intuitiveness, learning ease, distraction and aesthetics). Finally, participants ranked the lighting configurations from most to least preferred and provided their qualitative feedback.

E. QUANTITATIVE RESULTS

Regarding the lighting colour property, change noticeability and accuracy of interpretations, the root mean squared errors (RMSE) of the reported change counts and interpretations were calculated per participant for each configuration. Overall, three RMSE's per participant were obtained per configuration. Figure 5, displays a box plot of the errors.

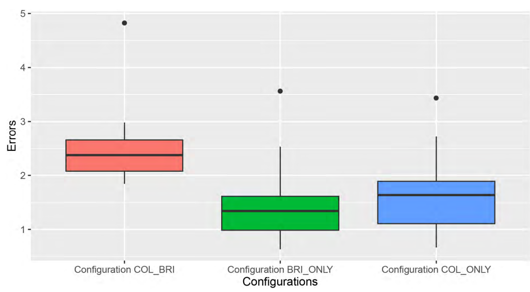

FIGURE 5. Boxplot of RMSEs of noticed changes and accuracy of interpretations adapted from [15].

An analysis of variance (one-way ANOVA with repeated measures) of the RMSEs was calculated using the R Project for Statistical Computing, where $F(2, 26) = 11.91$ and $p = 0.000212$. This revealed a statistically significant reported mean error difference ($p < 0.05$) among the three configurations. A Tukey post-hoc (HSD) test was conducted to determine, which reported errors differed. Reported errors differed significantly between configurations COL_BRI and BRI_ONLY ($p = 0.002$) and between COL_BRI and COL_ONLY ($p = 0.01$). However, there was no significant difference in reported errors between configurations BRI_ONLY and COL_ONLY ($p = 0.78$). This suggests that configuration COL_BRI was more susceptible to misinterpretations compared to configurations BRI_ONLY and COL_ONLY.

With reference to the heuristic evaluation of the configurations, in terms of desirable features, the sum of positive and negative perceived attributes were computed for each configuration. For a desired attribute, "strongly agree" carried weight of 2, "agree" = 1, "neither agree nor agree" = 0, "disagree" = −1 and "strongly disagree" = −2 and the opposite for a non-desirable attribute. User responses are presented in Figures 6, 7 and 8.

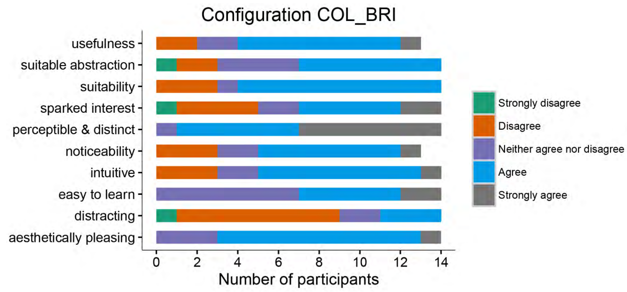

FIGURE 6. Heuristic evaluation of configuration COL_BRI adapted from [15].

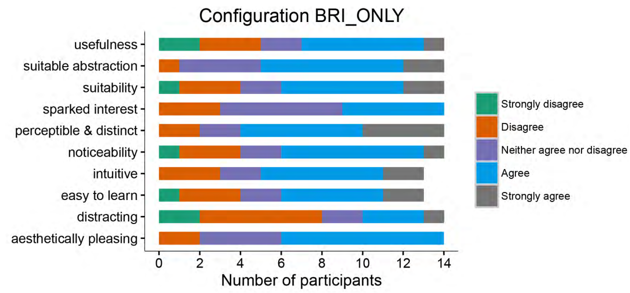

FIGURE 7. Heuristic evaluation of configuration BRI_ONLY adapted from [15].

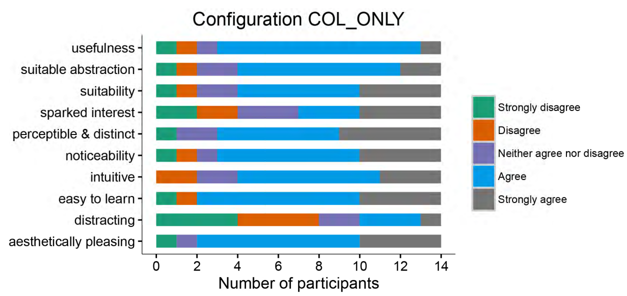

FIGURE 8. Heuristic evaluation of configuration COL_ONLY adapted from [15].

The configurations received a sum of 82, 56 and 105 for COL_BRI, BRI_ONLY and COL_ONLY respectively. A one-way ANOVA with repeated measures revealed a statistically significant difference in the mean of perceived positive attributes with $F(2, 18) = 8.456$ and $p = 0.0256$. A Tukey post-hoc (HSD) test revealed a statistically significant difference between only configuration COL_ONLY and BRI_ONLY ($p = 0.022$). This shows that participants had more positive attitudes toward configuration COL_ONLY compared to BRI_ONLY.

Finally, Figure 9 shows the ranking of preferences of the configurations with a rank of 3 being the most preferred and 1 being the least preferred. One-way ANOVA with repeated measures of the ranking revealed a statistically significant difference ($F(2, 26) = 15.95$ and $p = 3.01e - 05$)

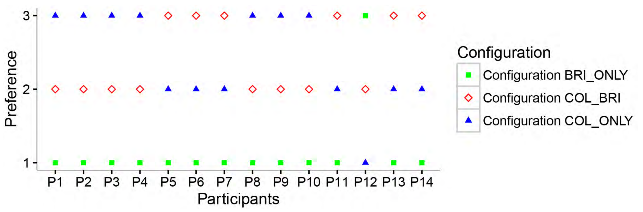

FIGURE 9. Scatter plot of user preference rank adapted from [15].

between user preferences of the configurations. A Tukey post-hoc (HSD) test showed that participants preferred configuration COL_ONLY to configuration BRI_ONLY ($p = 1.6e-06$) and configuration COL_BRI to BRI_ONLY ($p = 1.6e-06$). The preference difference between configurations COL_BRI and COL_ONLY was not statistically significant.

F. QUALITATIVE ANALYSIS

The qualitative results suggest the overarching themes that emerged following a semi-structured interview with our participants. Fifty-six statement cards were reviewed independently by two coders using a thematic analysis [51] approach. The main themes and sub-themes identified are now discussed.

1) POSITIVE PERCEPTIONS OF THE DESIGNS

Participants were generally accepting of the intuitive, convenient, informative, effortless, distinctive and simplistic nature of configuration COL_ONLY i.e. three colours at the same intensity. For example, one participant articulated,

"I like configuration COL_ONLY because one can easily distinguish the variation in activities." - P8

Moreover, some participants were vastly impressed by the dynamics and variety of feedback presented by configuration COL_BRI i.e. three colours with three intensity levels. For instance, one participant mentioned,

"I prefer configuration COL_BRI because it demonstrates changes in intensities and colour, which provides more information about the state or time in an activity." - P5

On the other hand, one person specified that configuration BRI_ONLY (one colour changing its brightness on three levels), was intuitive and discriminative in the following statement.

"I like configuration BRI_ONLY because it shows different levels of activity, distinct levels of luminance and it is intuitive." - P12

2) NEGATIVE PERCEPTIONS OF THE DESIGNS

The participant majority alleged that configurations COL_BRI and BRI_ONLY were overwhelmingly difficult to learn and portrayed inexplicit and confusing feedback e.g., one participant described his experience as follows,

"I was unable to memorize the meanings of colours and intensities with configurations COL_BRI and BRI_ONLY. Overall they were strange." - P9

However, participants were most displeased with configuration BRI_ONLY as they highlighted its complexity and generally conceded that it was meaningless and inadequate for an AAL setting. As an illustration, one participant mentioned,

"Configuration BRI_ONLY is not meaningful it doesn't give me information about activity changes with colours." - P5

In addition, participants generally articulated that important notifications could be easily missed with configuration BRI_ONLY. For example, one participant mentioned,

"with one colour and three intensity levels, it is more difficult to notice the changes in intensity. Also, when both colour and intensity changed in configuration COL_BRI, it was confusing." - P8

3) REASONS FOR AND AGAINST ADOPTION

A large majority of participants recognized the potential of ambient lighting displays on enhancing context awareness and social interaction, and also providing social support. While a few participants emphasized the therapeutic benefits of ambient displays and their ability to stimulate reflection, one participant pointed out the need for affordable LED solutions in AAL environments. These themes are reflected in the statements below.

My father has Parkinson's disease for 5 *years now and my mother would greatly benefit from such a system to provide better care for him."* - P9

P14 mentioned, *"With this installation I would think about my loved-one the whole day and the colours would add therapy to my life."*

"I am not sure because from my understanding Philips hue LEDs are extremely expensive and may not be viable for the regular consumer." - P2

However, some participants expressed uncertainty as they considered the privacy implications of such displays and demonstrated a lack of trust in the system. Moreover, one participant highlighted that context aware systems can be bad in excess in the following statement.

"I am not sure because I don't want to be 100% involved in my mother's activities. It is interesting but also invasive. It is a matter of virtual reality in the sense that you don't have the person but you have to trust a device that senses and processes the information. It is bad in excess. If you are able to manage it then it can be good. But if not managed it can replace the person..." - P5

G. DISCUSSION

This exploratory study aimed to assess three different lighting configurations to derive the best lighting parameters for encoding activity information in an AAL context. Confirming our expectations, more errors were experienced with configuration COL_BRI (three colours and three intensity levels), when compared to configurations BRI_ONLY and COL_ONLY. Our participants confirmed in their reflection, that configuration COL_BRI had too many changes i.e. both in hue and brightness, and consequently, misidentification was a common occurrence with this configuration. Based on our observation of the participants, changes in brightness were often misclassified as changes in colour.

There was no statistical significance for change noticeability for configurations BRI_ONLY and COL_ONLY. Notably, participants in their qualitative assessment mentioned that configuration BRI_ONLY (one colour changing its brightness on three levels), was too subtle and confusing.

Moreover, with configuration BRI_ONLY, some participants mentioned that they were more engaged in thinking only about one type of activity, while configuration COL_ONLY made them think about changes in activities while intuitively discerning the concept of time. We hypothesize that configuration COL_ONLY (3 colours at the same intensity) had fewer errors due to its easily distinguishable properties such as lighting colour with constant brightness. Overall, the results suggest that a higher cognitive load was experienced with configuration COL_BRI.

In retrospect, participants generally preferred configuration COL_ONLY for encoding activity information. By configuring the lights to show red for active, green for passive and blue for resting, participants generally indicated that the intuitive meaning of these colours were effortlessly mapped to activity levels.

With respect to suitability, participants articulated that lighting configuration COL_ONLY, had specific lighting properties, which made it particularly suitable for encoding activity information. These include, it provided a suitable abstraction of personal information and a clear mapping of activity information, its aesthetic quality, noticeability, intuitiveness, little distraction and ease of learning.

1) DESIGN GUIDELINES

Building on the previous research on ambient displays, the recommendations and experiment results, we now present nine design guidelines for the encoding of activity information for an AAL context.

1) Devise clear mappings for representing activity information with coloured lighting [30]. Brightness might not be appropriate as it often becomes confusing. However, if brightness is used, sudden changes in intensity should be avoided.
2) Abstraction is necessary to ensure the privacy of personal information [5], [19].
3) The lighting source should be aesthetically pleasing and should be smoothly integrated into the user's environment [4], [52].
4) Lighting changes should be intuitive [8] and match the user's mental model of the other person's activities [19]. Moreover, the lighting parameters used should create a dynamic understanding of the changes in the other person's environment.
5) Designers should not overwhelm its users with too many changes of lighting parameters.
6) When choosing the colour, the effects of colour on emotions should be considered. Red is suitable for high periods of activity, green for periods of relaxation and blue for resting periods. However, this can be based on personal taste, situational context, and cultural diversity. The use of one colour with varying intensities to represent different activity levels might not be acceptable as changes could be frequently indistinguishable.
7) Designers should consider the temporal nature of activity information and as such the duration of activities should be intuitively perceived by viewers. Moreover, it might be prudent to exploit light's parameters to show the history of an elder's activities in time.
8) Activity-based ambient lighting displays should provide therapeutic benefits, which is dependent on colour choice and can be used to encourage reflection, which is useful for enhancing social connectivity in AAL domains.
9) Activity-based ambient lighting displays should augment social interaction, however, it should not replace human-to-human communication.

V. STUDY TWO

Study two investigates the effects of activity awareness through an activity-based ambient lighting display on cognition, moods and to determine the users' willingness to adopt the ambient device. To achieve this, an intervention and a control condition with activity awareness as the only independent variable was necessary to isolate the effects of light alone from the effects of activity awareness through light. Recall that study one examined three activity-based lighting configurations, of which configuration COL_ONLY i.e. three colours at the same intensity was most preferred. Thus, in study two, configuration COL_ONLY was deployed to assess the effect of activity awareness through ambient lighting on cognition, moods, social connectedness and the users' willingness to adopt the new technology.

TABLE 2. Table showing participants' descriptive data.

Characteristics	No. of Participants	Percentage (%)
Gender		
Male	34	81
Female	8	19
Age		
18-24	38	90.5
25-34	4	9.5
Marital Status		
Single	42	100
Married	−−	−−
Nationality		
Italy	41	97.6
Ecuador	1	2.4
Occupation		
Student	42	100

A. METHODOLOGY

1) PARTICIPANTS AND STIMULI

Forty-two students of an Introduction to Programming Course at the University of Genova participated in this study and received course credits in return. The major demographic characteristics of the participants are displayed in Table 2.

Participants were mostly between 18 – 24 years and were primarily male Italians.

All subjects were tested individually and had normal or corrected-to-normal vision investigated with the Ishihara colour blindness test [50]. Prior to their participation in the study, each participant gave their written informed consent. In addition, they described their favourite elderly relative's hobbies and activities of daily living before the experiment. The participant majority revealed their elderly relatives were generally doing various activities around the home. For instance, Italian grandmothers (nonne) were typically engaged in cooking, gardening, watching television and reading while Italian grandfathers (nonni) were normally playing cards, taking casual walks, watching television and repairing items. There were a few grandparents who were in most cases resting due to ill-health. Subsequently, this information was used to design different simulations tailored to suit the participants' elderly relative's basal activities of daily living, which later served as inputs to our activity-based light display, exploiting a Wizard of Oz [53] design approach.

2) EXPERIMENTAL DESIGN AND INDEPENDENT VARIABLES

We employed a between-subjects experimental design methodology, where each participant was randomly assigned to one of two groups i.e. (test-aware and test-unaware). The test-aware participants were informed that the activity-based ambient lighting display rendered their elderly relative's activity levels in three categories, active (red), passive (green) and resting (blue) while the members of the other group were told that we were experimenting with various combinations of coloured light (red, green and blue) – test-unaware. The experiment was conducted in Italian.

Fitzsimons and Bargh confirmed that priming the names of one's parent can non-consciously activate the motivation to achieve academic success [49]. Thus, to stimulate more favourable goal-directed behaviour among participants, they were asked before the experiment to rank using a scale of 1 – 5 how well their closest elderly relative wanted them to succeed in school. However, only the test-aware participants were primed for 60 milliseconds [54], prior to the cognitive tasks. This was done in an effort to solicit the effect of awareness factor (the elderly counterpart) on the non-conscious activation of interpersonal goals.

In total, the experiment lasted for approximately sixty-minutes and participants were debriefed at the end of the entire experimental period.

3) DEPENDENT VARIABLES

Largely motivated by the non-visual effects of light demonstrated in [55], the study included memory and problem-solving cognitive tasks as well as mood, relationship closeness, and light evaluation measures.

- Moods – A pre- and post-test measure of self-reported moods was conducted using the self-assessment manikin (SAM) [56] scale. The SAM is a nine-point non-verbal pictorial measure, based on Russel's dimensional circumplex model of emotion [57], evaluating the subjective levels of valence (unpleasant-pleasant), arousal (activation-deactivation), and dominance (having a strong sense of control) in a participant's response to the stimulus. This lasted for approximately five minutes in sum. Furthermore, we attempted to measure involuntary responses such as electrodermal activity otherwise known as galvanic skin response (GSR), a sympathetic indicator of arousal [58] and electrocardiogram (ECG), which is used to calculate heart rate variability, an additional measure of emotions [59] using Shimmer sensing[2] devices. However, participants avidly expressed discomfort alluding to an invasion of personal privacy and obtrusiveness. This was common among all female participants. Accordingly, we discontinued use of the physiological instruments in this experiment.
- Social Connectedness – is defined in [60] as the "the experience of belonging and relatedness between people." In the beginning of the experiment and after 55 minutes of using the ambient light, participants ranked their subjective perception of interpersonal closeness with their elderly relative using the inclusion of other in the self (IOS) [61] scale. This is a seven-point pictorial scale utilizing two overlapping circles for assessing relationship closeness, more overlapping circles indicate higher levels of perceived relationship closeness. Overall, this task was approximately five minutes long.
- Implicit memory – this is a form of long-term memory, whereby an individual's behaviour is changed by prior experience, which is acquired without conscious recollection [62]. A word-stem completion task is a common measure of implicit memory [62]. In this study, an implicit memory task [63], investigated the memory effects of studying a list comprised of 31 simple Italian nouns [64], each word comprising four to nine letters. As a manipulation tactic, participants were given 5 seconds to rate the pleasantness of each of the 31 words. For a filler task, they were given a stem completion test to complete the names of 18 major cities. Thereafter, they were asked to complete a stem completion task, which included 12 target words among 63 distractors.
- Problem-Solving – Inspired by the work in [55], participants completed an embedded figures assignment [65], in which they were instructed to note five solution figures positioned at the top of the page and later identify the target answers among sixteen more complex figures. Participants were given a total of twenty minutes to complete this task and their responses were scored on a scale from zero to five points.
- Ambient lighting evaluation measure – Following the completion of the cognitive tasks and mood measure, participants gave their perceived estimation of the lighting characteristics (e.g., adoption, aesthetically pleasing,

[2]http://www.shimmersensing.com/

attention-demanding etc., see Figures 11 and 12) using a seven-point Likert scale along with their qualitative input. In addition, they assessed the implications of the light colour on productivity, concentration and relaxation. Notably, the activity-awareness questionnaire, included four questions that probed the participant's awareness of their elderly relatives activities and its influence on problem-solving, concentration, and relaxation. Moreover, the test-aware group was cross-examined with additional questions regarding adoption such as, ("Do you prefer to receive information about the activities of elderly relatives through a voice message, a text message or in the form of different colours of the light?"). Overall, this task was on average twenty minutes long.

4) PHYSICAL SETTING

The setting was identical to that of study one. However, to avoid the glare from the computer screen all tasks were entirely paper-based as demonstrated in the set-up in Figure 10. Also, window blinds were closed to prevent the influence of day-light.

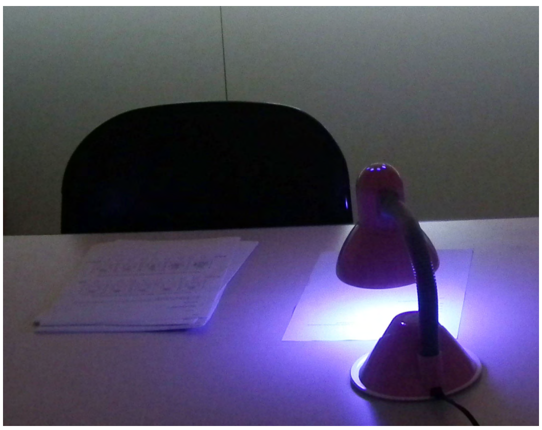

FIGURE 10. Experimental set-up for study two.

B. QUANTITATIVE FINDINGS

To assess the effects of activity awareness on relationship closeness, problem-solving, implicit memory, and moods (valence, arousal and dominance), we computed a one-way ANOVA of these measures between test-aware and test-unaware groups. We found no significant effects of activity awareness on relationship closeness, implicit memory and moods. In the case of this experiment, the participant majority had solid relationships with their elderly relatives and therefore, it was difficult to assess changes in social connectedness over short time intervals. Also, a few participants expressed perceptions of fatigue prior to the implicit memory task, which could have possibly influenced the results.

On the other hand, the findings suggest a significant effect of activity awareness on problem-solving with $F(1, 40) = 4.57$ and $p = 0.0387$. For a degree of freedom of 1 and a residual of 40, the F distribution requires an upper critical value of 4.085 to reject the null hypothesis [66]. Moreover, using the η^2 (Eta squared) measure yielded an effect size of 0.103, which is reasonably large according to the recommendations for the magnitude of effect sizes by Miles and Shevlin in [67].

A multivariate analysis of variance (MANOVA) was performed to find a significant mean variance in perceived subjective attributes between the test-aware and test-unaware groups. The results demonstrated no statistical significance and yielded a p-value of 0.3987. Figures 11 and 12 illustrate the mean ratings of perceived subjective attributes of the lighting configuration for the two groups.

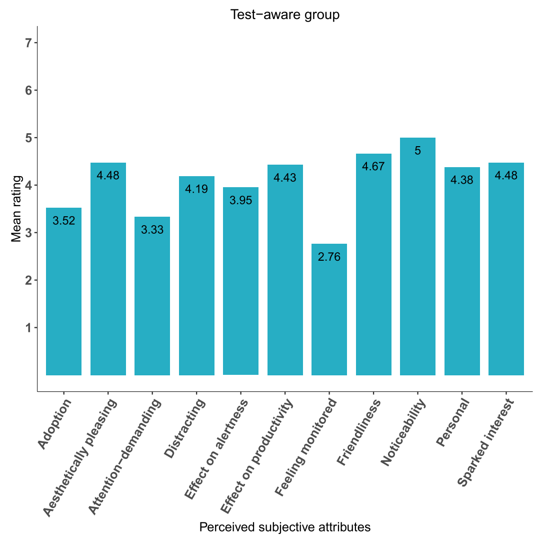

FIGURE 11. Experimental results showing the test-aware participants' perceived estimations of the lighting characteristics.

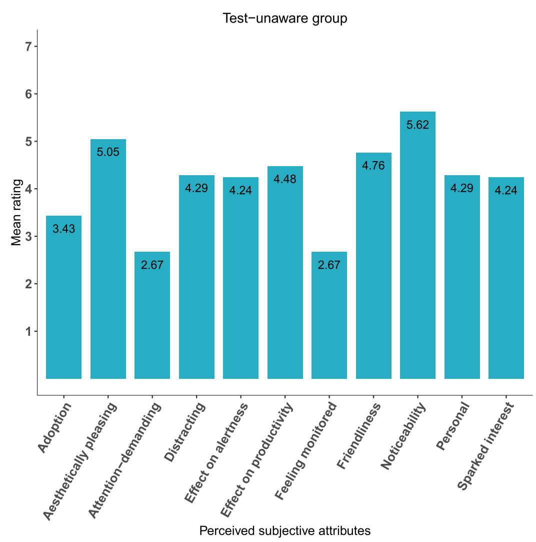

FIGURE 12. Experimental results showing the test-unaware participants' perceived estimations of the lighting characteristics.

Notwithstanding the lack of a statistically significant difference, participants in both groups generally held positive attitudes toward the ambient lighting display, with more favourable attitudes on aesthetics, noticeability, and friendliness of the installation. Regarding attention, the test-aware group of participants seemed to have utilized more attentional resources than the test-unaware group, which could be attributed to the more meaningful representation of activity information of their loved-ones and as such prompted them to try to understand their ADL patterns. A similar trend was also observed in [19], where caregiver participants were actively engaged in deciphering the activities of their elderly counterpart. This implies that activity-based lighting displays may directly or indirectly influence users to divert their attention from their primary tasks. In the next section, we discuss our qualitative findings.

C. QUALITATIVE ANALYSIS

Three hundred and ninety nine responses to a semi-structured post experiment interview were translated with the assistance of a native Italian and an upper intermediate Italian speaker. Subsequently, the statements were reviewed independently by two coders using the thematic analysis [51] methodology. Overlapping concepts were then clustered to identify broad themes and categories that may play a vital role in assessing the lighting design dimensions and implications of activity awareness through ambient light on cognition, moods and perceived usefulness in AAL environments. These underlying themes and sub-themes were identified throughout the study.

1) VISIBLE LIGHT PATTERNS

All participants recognized to some degree the changes in the light patterns. The participant majority identified lighting features including the following:

- colour variation
- colour temperature
- rate of change
- reflection properties
- brightness

These features are encapsulated within the following statements.

"I observed the colour of the light reflecting on the sheet. Warm light was more distinctive." - P23 (test-aware)

"The light changes colour, often gradually moving from shades of green to yellow to red and blue." - P29 (test-aware)

Notably, it was observed that 24% of the participants misclassified green as yellow. Perhaps, this can be attributed to the after image effect [68], where exposure to blue light produced a yellow aftermath.

2) POSITIVE PERCEPTIONS OF THE DESIGN

Participants generally displayed positive attitudes and perceptions toward the system. In particular, most interviewees reported on the ambient light's effective usability features including the following.

- aesthetic appeal
- friendly atmosphere
- smooth transition
- degree of reflection
- non-distracting, automatic, innovative, intriguing and fun nature
- positive influences on vision, productivity, and psychological processes

These example statements describe aspects of the above mentioned sub-themes.

The change in colours were beautiful and I guess it would be fun to have a lamp like this. - P1 (test-unaware)

The changes of the light favours concentration, without being distracting as it has a smooth transition between rapid changes of the light. - P31 (test-aware)

Green and blue are light colours that enhance reading and therefore it is easy to keep writing, red tones, however, are nice and friendly... - P29 (test-aware)

A few participants explicitly reported that the light seemingly had a helpful effect on problem-solving strategies. For instance, one person mentioned the following.

"It somehow felt that the light was highlighting moments of difficulty and some moments of ease as it relates to the problem-solving tasks. It appeared as though it was helping me to find the words." - P24 (test-aware)

3) NEGATIVE PERCEPTIONS OF THE DESIGN

Features such as (i) lighting position, (ii) over-illumination, and (iii) annoyance or distraction effects of warm colour temperatures (red), were reported. For example, one participant alluded to discomfort in the following claim.

"The red light had a high intensity. Therefore, it made me a little uncomfortable while reading." - P29 (test-aware)

Also, the lighting source, position, and reduced scattered intensities were also negatively perceived by a few participants. This is reflected in the following statement.

The lamp is very short, therefore the light was not well diffused." - P11 (test-unaware)

On the other hand, one person expressed interest in being able to customize the lighting colours. This implies that the position and intensity of the lights cannot be generalized but is subject to users' preferences.

4) COLOURED LIGHT ON PRODUCTIVITY, CONCENTRATION AND MOODS

The main concepts identified and the percentage of all participants responses are depicted in Table 3.

Some participants noted positive effects of the ambient light on productivity alluding to sensations of major concentration and relaxation, with a handful emphasizing the light's helpful influence on cognitive tasks. However, certain participants recounted that they were not influenced by the light during the problem-solving task. On the other hand, quite a few disclosed that they were distracted mainly by the red light while some reported agitation primarily because of the red light and minimally due to the green light. A small number of participants, observed the light's influence on time pressure while performing cognitive tasks. Example recollections of the implications on problem-solving are illustrated below.

TABLE 3. Table showing the main concepts identified from the participants' responses.

Concept	Percentage of Participants (%)
Coloured light on boosting productivity	
boost productivity	24
helpful influence	7
not influenced	26
distraction	29
agitation	7
time pressure	7
Coloured light on boosting concentration	
green	38
red	26
blue	24
not influenced	12
Coloured light on stimulating relaxation	
blue	57
green	31
red	10
not influenced	2

"I was pleasantly influenced by the change from red to blue, at moments when I could not remember the words, it aided my memory." - P22 (test-aware)

"Sometimes the tones of the light made me relaxed and sometimes it made me concentrate more, other times I was distracted when it was too strong." - P6 (test-unaware)

"The red agitated me and made me feel the pressure of time." - P35 (test-aware)

"The light did not influence me in any way, I saw the changes every now and then but I was focused on what I was doing." - P25 (test-aware)

In both experimental groups, the participants generally made reference to the influence of the lighting colours on concentration and moods. Specifically, a large number of participants asserted that green light was most effective for boosting concentration, while some of the interviewees emphasized that red light stimulated concentration. However, certain participants said blue light had high concentration effects while a scant amount reported no effects on concentration.

With respect to the positive influences of lighting colour on relaxation, more than half of the participants emphasized that blue light activated feelings of relaxation while performing cognitive tasks, while a considerable amount reported that they were generally relaxed with the green light. However, a few reported positive influences of the red light on relaxation while hardly any of the participants reported no influence at all.

In retrospect, more informative remarks were encountered in the test-aware group's assertions of the effect of activity awareness through coloured lighting on cognition, productivity and moods. We will discuss these insights in the next subsection.

5) ACTIVITY AWARENESS THROUGH LIGHTING ON PRODUCTIVITY, CONCENTRATION AND MOODS

The major concepts identified and the percentage of all participants responses are portrayed in Table 4. A large majority of the test-aware group participants said that they were most productive in the passive activity level (radiates green light) while several inferred that their productivity level increased in the active activity level (emanates red light). On the other hand, the remaining few articulated that the resting activity level (displays blue light) was beneficial for boosting productivity.

TABLE 4. Table showing the main concepts identified from the test-aware participants' responses.

Concept	Percentage of Participants (%)
Activity light on boosting productivity	
passive	43
active	33
resting	24
Activity light on boosting concentration	
active	43
passive	38
resting	19
Activity light on stimulating relaxation	
resting	57
passive	14
active	14
all three	5
not influenced	10

Revisiting the notion of activity awareness on productivity, a few of the test-aware participants alluded to possible non-conscious motivational influences of activity awareness through lighting on social presence and performance on cognitive tasks. This is reflected in the following statements.

"My uncle's desire for my success could have unconsciously motivated me to succeed during the test." - P26

"Her personal presence was felt and this stimulated me to perform well for sure." - P35

Concerning the effect of peripheral activity awareness through lighting on concentration and reasoning, we deduce a possible relation between colour symbolism and the implicit meaning of the specific activity level e.g., an implicit link between 'active (red)' and 'fast' or 'resting (blue)' and 'quiet', which is reflected in the following statements.

"Active, the red colour made me reason faster." - P34

"Resting, blue light is quiet and to concentrate I need absolute silence." - P22

"Passive, in the sense that the green light did not push me to make an effort to see what I am doing because it was bright and neutral in colour." - P29

Furthermore, the active activity level was deemed as most effective for boosting concentration by the participant majority while a few regarded the passive activity level as effective for concentration boost and the others favoured the resting state for its positive influence on concentration.

Again regarding the influence of peripheral activity awareness through lighting on relaxation, we gather a possible association with the implicit meaning of the colour and the actual activity itself. For example, two participants described this effect in the following statements.

"Resting, because blue is relaxing, in fact it has the same effect everywhere." -P37

"Resting tended to make me feel more relaxed, because I associated the colour blue to a state of calm and resting." - P28

In hindsight, resting was most favoured among the participants for its positive influence on relaxation while a few participants acknowledged the benefits of the passive and active activities on relaxation. Specific benefits of the resting activity on relaxation discussed among test-aware participants are illustrated below.

- the serene nature of blue
- positive effects on sensations of calmness and peacefulness
- the feeling of time pressure gradually decreased
- a triggered a sense of security and feeling of accomplishment
- provides good readability, aids concentration and reduces distraction

6) MEDIA CHOICE FOR AWARENESS INFORMATION

Of the twenty-one test-aware participants interviewed, 76% preferred traditional information sources such as voice and text for staying connected with loved ones. However, the remaining 24% were intrigued by the possibility of peripheral displays in AAL environments owing to its 'quiet' and intuitive nature. Examples of the participant's feelings are shown below.

"The different colours of the light indirectly, stimulates attention, while written or vocal messages would be disruptive." - P22

"The idea of light is very interesting, but the changes tend to distract a little. Maybe not with the lamp while at work, but the light is certainly more immediate and intuitive." - P29

"I think I can communicate with my grandparents with voice messages. I would change my mind if other modes of communication were as easy as this." - P38

VI. GENERAL CONCLUSIONS

Activity-based ambient displays can present significant benefits and challenges to the mental, social and emotional functioning of caregivers in AAL environments. Notably, work and study environments are uniquely challenging contexts for presenting ambient information. Exploiting a user-centered design approach, we sought to elucidate the implications of activity-based lighting displays on productivity, concentration, and moods, and based on this understanding glean compelling user insights on critical design features that will inspire innovation of such technologies.

In keeping with the universal principles of accessible and inclusive design, we now articulate a set of key design sensitivities that should be observed when designing activity-based lighting displays.

- Light sensitivity – Over-illumination can be irritating to the eye and negatively affect performance on primary cognitive tasks [69]. In our study, we found that a number of participants experienced negative effects induced by bright light. One plausible solution is to moderate the intensity of bold colours such as red to minimize irritation and avoid disruptive effects on primary tasks.
- Spatial position – the spatial position affects the perception of activity information and may cause distraction on primary cognitive tasks. Hence, designers should not position the light source directly in the field of view but more on the periphery of the user's attention. In the context of AAL, this may support the management of distraction, which is considerably greater in older adults [70] and to avoid distraction effects for caregivers in their working environments.
- Sensor obtrusiveness - We found that participants were generally apprehensive regarding the notion of wearable ECG and GSR sensors, a similar pattern reported in [71]. This can be attributed to the position of the ECG electrodes on very sensitive parts of the body such as the chest leads and the discomfort caused by the GSR sensor. A viable solution is to explore lightweight wearable sensors that are gender neutral and minimally invasive along with additional physiological measurements reported by Kreibig [59] for evaluating the emotional implications of the display.

Based on our qualitative results, the use of activity-based ambient displays show promise for sustaining awareness while simultaneously depicting positive influences on concentration, relaxation and positive moods in work environments. This is mainly attributed to coloured lighting, which was enjoyed by our participant majority. Additionally, participants were more accepting towards the intriguing, intuitive and creative characteristics of the display, while asserting its influence on positive moods [59] such as contentment (serenity, calmness, peacefulness, and relaxation) and relief (safety).

Moreover, the results show positive implications of coloured lights on concentration and productivity, which are consistent with previous research insinuating unconscious influences of colour on cognition and behaviour through learned associations [44]. Traditionally, red is activating, stimulating and exciting [72], while other studies have suggested negative implications of red on performance due to its association with psychological danger or failure in achievement scenarios [73]. Conversely, in our study, we found that the test-aware participants had perceptions of higher concentration boost with the active activity level, which emanated red light. We posit that this can be attributed to an implicit link between the stereotype associated with the word or activity itself as demonstrated in [74] coupled with the psychophysical influence of the coloured lighting exposure on the participant. Also, the subjective experience of increased time pressure with the red activity light is consistent with the work by Delay and Richardson in [36], whereby subjective estimates of time runs faster with higher light intensities. From the qualitative findings, we can infer that activity-based ambient lighting displays can serve a dual function as a source of activity information of the elderly counterpart while simultaneously creating a relaxing and pleasant atmosphere, together with a positive modulation of cognition and moods.

Although traditional media was by far the most preferred information source for activity information, the qualitative results show promise for activity-based ambient displays to sustain social connections and stimulate productivity while working through induced social presence, with potential offerings of immediate and intuitive awareness of ADLs in AAL contexts. Arguably, subjective feelings of social connectedness in long-term interpersonal relationships tends to be relatively stable over time [75], [76].

Notwithstanding these benefits, we identified certain areas for improvement of activity-based ambient displays from the participants' responses. We observed the need for customization of properties (such as colour, intensity, position) of the lighting system in order to infuse flexibility in our design.

In summary, this research provided insights into the perceptions of the lighting parameters to inform the design of an ambient lighting display to portray activity information for an AAL context and explored the implications and practicality of such awareness technologies in AAL environments. The research outcomes indicate an overall positive attitude towards the technology, as well as the potential influence of activity-awareness through lighting on mood enhancement, concentration and productivity in work-related environments. From the experimental results, we posit that caregivers in their work environments could potentially benefit from a mediated connection with their elderly counterparts.

In addition, the results indicate the relevance of lighting parameters such as colour to encode activity information for easy interpretation, minimal distraction and reduced mental effort to facilitate information access and create an aesthetically pleasing and meaningful interaction.

Notably, constraints regarding distractions, privacy and trust in working environments can create a challenge for designers in the AAL field. However, to accommodate perceptual deficiencies, building on previous research, this work culminates with in a series of design guidelines and sensitivities to be observed when designing activity-based ambient lighting displays for AAL settings. Accordingly, these insights could have positive implications for the design of future ambient lighting displays within an AAL context because of its great potential for increasing awareness, engagement and positive emotional responses.

A. LIMITATIONS AND FUTURE WORK

This work is not without limitations. First, we capitalized on opportunistic sampling, therefore the participants recruited in this work were not necessarily representative of all stakeholders within the AAL domain. Considering only a specific target group (caregivers) were examined in this work, findings should not be generalizable to the elderly on a whole as older adults are usually challenged with changes in their colour perception and pupillary excursion capability (i.e. older eyes are less sensitive to short wavelengths (e.g., blue) and less light reaches the retina, particularly under low light conditions) [77]. Therefore, an additional study with more variability in age would be useful for evaluating the perceptions of older adults on lighting features and assessing the implications of activity awareness through coloured lighting on cognition and behaviour.

Second, the quantitative findings exhibited a change in neither implicit memory nor moods. Rather, the qualitative findings provided insights into how the activity-based ambient lighting displays affected memory, mood enhancement and behaviour in response to the stimulus. To achieve a more informed and extensive evaluation of the changes in psychophysical behaviour, a long-term study is required with a sufficiently larger sample size, accompanied by the use of wearable unobtrusive physiological measurements.

Third, in a real AAL scenario, we acknowledge that it might be prudent to combine different types of effectors (ambient displays) depending on the specific activity performed and the physical location of the users. The hue lamp in its current state lacks portability and is limited to the homes or work environment of potential users. Therefore, it is reasonable to consider how to exploit everyday objects to enable design flexibility and the ubiquitous access to activity information for both user groups. This will be implemented in the near future.

To conclude, for future work we will consider a detailed evaluation of a real-time activity-based ambient lighting display that will be deployed in a controlled or semi-controlled AAL environment. In this study, we aspire to ascertain further insights into how the system influences activity awareness and fosters the maintenance and strengthening of social connectedness over time.

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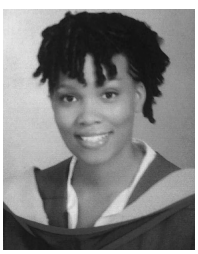

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