Evaluating Human Activity-Based Ambient Lighting Displays for Effective Peripheral Communication

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Ambient Assisted Living (AAL) applications leverage pervasive sensing and ambient intelligence technologies to enable older people to live independently and to support their social inclusion and connectedness. Wearable sensors can be used to gather the elderly's activities of daily living (ADLs) data, thus enabling remote monitoring. Lately, ambient displays have been deployed to relay activity information in the periphery of the caregivers' attention in order to increase awareness of the activities of the elderly and to create a sense of connectedness. Moreover, there is accumulated evidence demonstrating the ability of ambient displays to influence and promote social connectedness between the elderly and their caregivers. In recent years, intelligent ambient lighting, a subclass of ambient displays, is emerging as an effective tool for conveying physical activity information. Existing literature suggests lighting encodings or configurations combining color, rate of change, position and brightness to communicate such information. Within AAL, there is little empirical evidence surrounding ambient lighting encodings that support this cause effectively. In this paper, we present an exploratory study investigating how potential caregivers perceive and interpret ambient lighting configurations for presenting activity information of the elderly. User preference, change noticeability and accuracy of the interpretation of three ambient lighting configurations were evaluated.

CCS Concepts

•Human-centered computing → Ubiquitous and mobile computing; •Ubiquitous and mobile computing → *Ambient Intelligence;*

BODYNETS 2016, December 15-16, Turin, Italy

Keywords

context awareness; ambient lighting displays; ambient assisted living; social connectedness

1. INTRODUCTION

Ambient intelligent solutions can have positive implications on improving the health and well-being of older adults [10]. A widely accepted definition of Ambient Intelligence (AmI), was introduced in 2001 by the ISTAG [9], an EU advisory group, to demonstrate a new approach to designing intelligent environments with a user-centric focus on improving the quality of life. An excerpt from the ISTAG mantra [9], 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." Within AmI environments, such as ambient assisted living (AAL), human activity recognition (HAR), i.e. the recognition and monitoring of activities of daily living (ADL) is a distinctive feature to support independent living among older adults. A common approach to HAR, includes the deployment of wearable sensors such as accelerometers and gyroscopes to support context awareness [26].

As we experience a new wave of AAL technologies, privacy and protection of personal information remains as one of the biggest challenges surrounding the continuous monitoring of people [3, 10]. Explicit presentation of users' activities such as "walking", "sleeping", "cooking" among others often cause users to express privacy concerns about their personal information. Pedersen and Sokoler in [24], proposed a "kind of shielding" of personal activity information through abstraction, exploiting features such as visual or auditory cues to provide "non-attentional demanding awareness".

Peripheral awareness is defined in [24] as, "our ability to maintain and constantly update a sense of our social and physical context." Ambient information systems, an application area of ambient intelligence, is grounded in the theories of peripheral awareness, whereby information is subtly portrayed in the periphery of the user's attention. This allows users to receive information in the background while performing other tasks in the foreground. In a digital era, people are often inundated with information, from emails to a variety of social media applications [20]. Ambient displays are part of the solution to reducing the amount of information mentally processed by providing an overview of the content. Moreover, ambient displays [16], capitalize on the principle of calm technology [28], as they transition effortlessly from the foreground to the background of the user's attention. Thus, a critical feature of ambient displays is their capability to be perceived at a quick glance, which triggers pre-attentive processing to reduce the user's cognitive load. Moreover, ambient displays should not distract users from performing their main tasks. In AAL environments, ambient displays hold promise as they can present information to users whenever and wherever needed, to support context awareness and to improve interpersonal relationships as demonstrated in [21].

Importantly, when designing ambient lighting displays the designer has to establish a context for decoding the information [22]. Specifically, in order to grasp the information received, the viewer has know the meaning of each lighting characteristic. In certain instances, users can understand intuitively or they can be explicitly told about the significance of the encoding [20, 22]. Occasionally, there are discrepancies between the designer's intention of the encoding and the viewers interpretation of the encoding. In reality, what matters most is what is understood by the viewer and not the designer's intention [22].

This paper builds on the proposal in [3, 4, 7] to present activity information using subtle ambient lighting displays to support social connectedness and context awareness between the elderly and their caregivers. Following this proposal, a smartphone activity recognition system was developed using the hybrid SVM-HMM model with an overall accuracy of 99.7% [5]. This model was used to classify six activity states namely, walking, walking upstairs, walking downstairs, standing, laying and sitting. To provide abstraction and privacy protection, the complexity of activity states was reduced to activity levels [6]. In this work, the six activity states have been discretized into three activity levels i.e. "resting", "passive" and "active". This abstraction of activity states into activity levels was based on user generated mappings. Users mapped activity states to levels based on their jobs and opinions of which activity states they considered to be active, passive or resting. As a continuation of the work in [5, 6], we seek to investigate how ambient lighting parameters can be exploited to encode activity information. What is lacking for designers are consistent design guidelines for encoding activity information within an AAL context.

In this paper, we focus on the design and evaluation of three lighting configurations taking into consideration position of the light source, frequency of light changes and lighting color properties (hue and brightness). Inspired by the work in [19], 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. Based on the aforementioned requirements we evaluated:

- noticeability and accuracy of interpretations of the lighting configurations. We assume a glanceable ambient light, which gives clear information 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.

2. RELATED WORK

In an AAL setting, the integration of lighting, the Internet and sensors can realize systems that go beyond illumination. In particular, lighting through the Internet of Things (IOT), is capable of sensing and communicating vast amounts of data from 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 discussed in [3, 20] make it ideal for encoding physical activity information. Within AAL, the rendering of activity information through ambient displays has demonstrated potential for strengthening connectivity between the elderly and their caregivers [21]. 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 snowgloble reflected a bright orange light accompanied by fluttering snowflakes. Similarly, the Casablanca Intentional Presence Lamp [13], conveyed presence information to two remote users using different images and colour. In another scenario, the Lumitouch [2] deployed ambient light for emotional communication. However, in these studies the information encoded was varied and as such was lacking in a consistent framework for encoding activity information especially for an AAL context.

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 [1]. 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 [17] 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 [11] 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 [11]. The Pediluma ambient display, is a shoe accessory that uses one colour (green), with varying intensities to visualize the wearer's physical activity [15]. 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 combination of lighting parameters to encode 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 the information influenced the users' activity 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 [12]. As Gladwell argues, rapid cognition is not always correct, 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.

A considerable amount of work has been published on design guidelines for the design [8, 25, 27] and assessment of ambient displays [16, 18]. 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. [19] 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 [19], 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 one 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, the authors in [23] 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 [6], 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.

3. METHODOLOGY

As we strive for more appropriate guidelines for encoding activity information to fit an AAL context, a controlled experiment was designed with two parts. Specifically, 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 illicit feelings of social connectedness. A review of published work and a user-centered approach were adopted to design three lighting configurations.

3.1 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 were as follows: 64.3% were between $25-34$, while 21.4% were between $18-24$ and 14.3% were between $35-44$ years. The sample was comprised of 85.7% males and 14.3% females, while 66.7% were students and 33.3% were employed. The sample was predominantly Italian (5 males and 1 female), followed by Pakistani (3 males), with small numbers of other nationalities such as Tunisian (1 male), Colombian (1 male), Iranian (1 male), Indian (1 female) and Lebanese (1 male). All participants had normal or corrected-to-normal visual acuity and were tested for colour vision deficits using the Ishihara color blindness test [14]. Participants were informed of the required procedure and signed their consent form.

3.2 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 social connectedness and context awareness. Accordingly, the lighting parameters deployed must be glanceableable, 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 color properties) on encoded activity information, we had three main findings:

- Ambient light must be glanceable, 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 [3], participants were more in favour of lighting applications that can be easily incorporated in their 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 more 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 color property. Also, the amount of time a user stays in an activity level is another dimension that can be overtly relayed (represented by lighting color property) or covertly relayed (intuitively decerned by users). Based on these findings, three lighting configurations (X,Y,Z) were designed.

Configuration X can convey both changes in activity levels and also the temporal duration of stay in a particular level. Figure 1, shows configuration X, where red, green and

Figure 1: Lighting Configuration X

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 [6], 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 color 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 [15], configuration Y exploited changes in brightness of a single default green color to convey changes in activity levels. Temporal duration of activity levels was not overtly conveyed. Configuration Y is depicted in figure 2.

Figure 2: Lighting Configuration Y

To convey changes in activity levels, configuration Z employed changes in lighting color in the same manner as configuration X. Like configuration Y, the temporal duration of activity levels was not overtly represented. Figure 3, demonstrates lighting configuration Z.

Figure 3: Lighting Configuration Z

3.3 Experiment setup and procedure

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 color 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 the network. A hand held tally counter was used by participants to monitor the changes in lighting color. The experiment was divided into two phases using a repeated measures design methodology. Figure 4, illustrates an example of a participant performing the experiment.

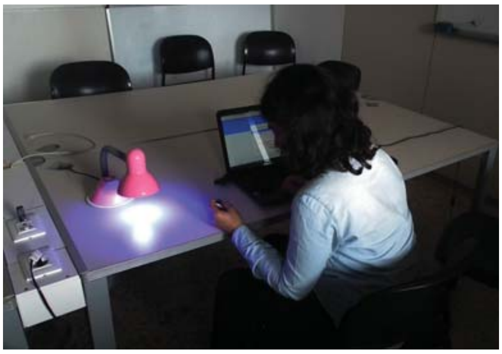

Figure 4: An example of a participant performing experiment

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 X, Y and Z 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 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 X, Y and Z 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.

4. RESULTS

Regarding the lighting color 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.

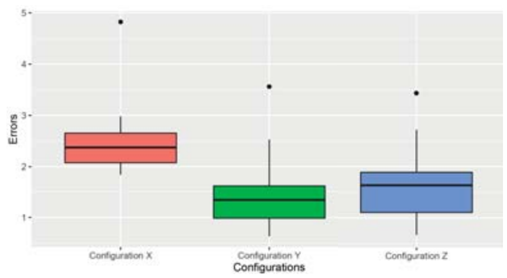

Figure 5: Boxplot of RMSEs of noticed changes and accuracy of interpretations

An analysis of variance (one-way ANOVA) of the RMSEs was calculated using the R Project for Statistical Computing. An F value of 7.6 with a p value of 0.00156 was obtained. 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 X and Y ($p = 0.002$) and between X and Z ($p = 0.01$). However, there was no significant difference in reported errors between configurations Y and Z ($p = 0.78$). This suggests that configuration X was more susceptible to misinterpretations compared to configurations Y and Z.

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.

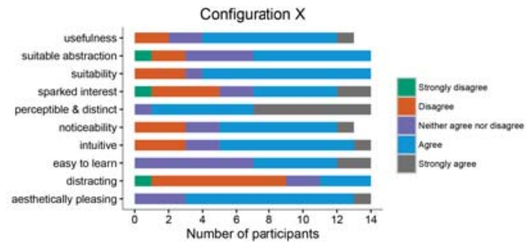

Figure 6: Heuristic evaluation of Configuration X

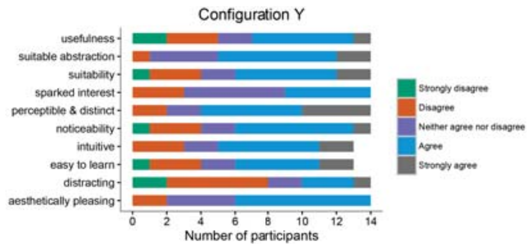

Figure 7: Heuristic evaluation of Configuration Y

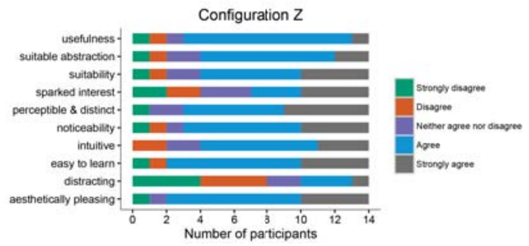

Figure 8: Heuristic evaluation of Configuration Z

The configurations received a sum of 82, 56 and 105 for X, Y and Z respectively. A one-way ANOVA revealed a statistically significant difference in the mean of perceived positive attributes with $F = 4.05$ and $p = 0.029$. A Tukey post-hoc (HSD) test revealed a statistically significant difference between only configuration Z and Y ($p = 0.022$). This shows that participants had more positive attitudes toward configuration Z compared to Y.

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. A one-way ANOVA of the ranking revealed a statistically significant difference ($F = 23.93$ and $p = 1.65e - 07$) between user preferences of the configurations. A Tukey post-hoc (HSD) test showed that participants preferred configuration Z to configuration Y ($p = 1.6e - 06$) and configuration X to Y ($p = 1.6e - 06$). The preference difference between configurations Z and X was not statistically significant.

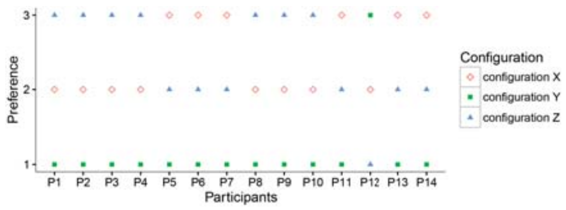

Figure 9: Scatter plot of user preference rank

5. DISCUSSION AND CONCLUSION

The aim of this study was 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 X (three colours and three intensity levels), when compared to configurations Y and Z. Our participants confirmed in their reflection, that configuration X 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 participants, changes in brightness were often misclassified as changes in colour.

There was no statistical significance for change noticeability for configurations Y and Z. Notably, participants in their qualitative assessment mentioned that configuration Y (one colour changing its brightness on three levels), was too subtle and confusing. They generally articulated that important notifications could be easily missed with this configuration. 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 X, it was confusing." Moreover, with configuration Y, some participants mentioned that they were more engaged in thinking only about one type of activity, while configuration Z made them think about changes in activities while intuitively discerning the concept of time. We hypothesize that configuration Z (3 colours at the same intensity) had less 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 X.

In retrospect, participants generally preferred configuration Z for encoding activity information. When the lighting configuration was shown the colour of the lights was 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 Z, had specific lighting properties, which made it particularly suitable for encoding activity information. These include, it provided suitable abstraction of personal information and a clear mapping of activity information, its aesthetic quality, noticeability, intuitiveness, little distraction and ease of learning. However, with the introduction of ambient lighting systems in AAL environments, privacy was a major concern among our participants.

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

- Devise clear mappings for representing activity information with lighting. Brightness might not be appropriate as it often becomes confusing. However, if brightness is used, sudden changes in intensity should be avoided.
- Abstraction is necessary to ensure the privacy of personal information.
- Lighting changes should be intuitive and match the user's mental model of the other person's activities. Moreover, the lighting parameters used should create a dynamic understanding of the changes in the other person's environment.
- Designers should not overwhelm its users with too many changes of lighting parameters.
- The lighting source should be aesthetically pleasing and should be smoothly integrated into the user's environment.
- When choosing the colour, the effects of colour on affect 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.
- 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.

In summary, the findings of our exploratory study 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. The study shows the relevance of lighting parameters such as colour to encode activity information for easy interpretation, minimal distraction and reduced mental effort. This could have implications for the design of future ambient lighting displays within an AAL context because of its great potential for increasing awareness and affective responses.

6. ACKNOWLEDGEMENTS

This work was supported in part by the Erasmus Mundus Joint Doctorate (EMJD) in Interactive and Cognitive Environments (ICE), which is funded by Erasmus Mundus under the FPA no. 2010-2012. Many thanks to the participants who took part in this experiment.

7. REFERENCES

[1] P. Burns, C. Lueg, and S. Berkovsky. Activmon: encouraging physical activity through ambient social awareness. In *CHI'12 Extended Abstracts on Human Factors in Computing Systems*, pages 2363–2368. ACM, 2012.

[2] A. Chang, B. Resner, B. Koerner, X. Wang, and H. Ishii. Lumitouch: an emotional communication device. In *CHI'01 extended abstracts on Human factors in computing systems*, pages 313–314. ACM, 2001.

[3] K. Davis, L. Feijs, J. Hu, L. Marcenaro, and C. Regazzoni. Improving awareness and social connectedness through the social hue: Insights and perspectives. In *Proceedings of the ITAP'16: International Symposium on Interactive Technology and Ageing populations*. ACM, In press, 2016.

[4] K. Davis, J. Hu, L. Feijs, and E. Owusu. Social hue: A subtle awareness system for connecting the elderly and their caregivers. In *Pervasive Computing and Communication Workshops (PerCom Workshops), 2015 IEEE International Conference on*, pages 178–183. IEEE, 2015.

[5] K. Davis, E. Owusu, V. Bastani, L. Marcenaro, J. Hu, C. Regazzoni, and L. Feijs. Activity recognition based on inertial sensors for ambient assisted living. In *2016 19th International Conference on Information Fusion (FUSION)*. IEEE, 2016.

[6] K. Davis, E. Owusu, J. Hu, L. Marcenaro, C. Regazzoni, and L. Feijs. Promoting social connectedness through human activity-based ambient displays. In *Proceedings of the ITAP'16: International Symposium on Interactive Technology and Ageing populations*. ACM, In press, 2016.

[7] K. Davis, E. Owusu, C. Regazzoni, L. Marcenaro, L. Feijs, and J. Hu. Perception of human activities a means to support connectedness between the elderly and their caregivers. In *Proceedings of the 1st International Conference on Information and Communication Technologies for Ageing Well and e-Health*, pages 194–199. SCITEPRESS, 2015.

[8] A. Dey, J. Mankoff, and A. K. Dey. From conception to design, a practical guide to designing ambient displays. 2003.

[9] K. Ducatel, M. Bogdanowicz, F. Scapolo, J. Leijten, and J.-C. Burgelman. Scenarios for ambient intelligence in 2010. *Office for official publications of the European Communities*, 2001.

[10] P. L. Emiliani and C. Stephanidis. Universal access to ambient intelligence environments: opportunities and challenges for people with disabilities. *IBM Systems Journal*, 44(3):605–619, 2005.

[11] J. Fortmann, T. C. Stratmann, S. Boll, B. Poppinga, and W. Heuten. Make me move at work! an ambient light display to increase physical activity. In *2013 7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops*, pages 274–277. IEEE, 2013.

[12] M. Gladwell. *Blink: The power of thinking without thinking*. Back Bay Books, 2007.

[13] D. Hindus, S. D. Mainwaring, N. Leduc, A. E. Hagström, and O. Bayley. Casablanca: designing social communication devices for the home. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 325–332. ACM, 2001.

[14] S. Ishihara. *Test for colour-blindness*. Kanehara Tokyo, Japan, 1987.

[15] B. Y. Lim, A. Shick, C. Harrison, and S. E. Hudson. Pediluma: motivating physical activity through contextual information and social influence. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction*, pages 173–180. ACM, 2011.

[16] J. Mankoff, A. K. Dey, G. Hsieh, J. Kientz, S. Lederer, and M. Ames. Heuristic evaluation of ambient displays. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 169–176. ACM, 2003.

[17] V. Mateevitsi, K. Reda, J. Leigh, and A. Johnson. The health bar: a persuasive ambient display to improve the office worker's well being. In *Proceedings of the 5th Augmented Human International Conference*, page 21. ACM, 2014.

[18] T. Matthews, G. Hsieh, and J. Mankoff. Evaluating peripheral displays. In *Awareness Systems*, pages 447–472. Springer, 2009.

[19] A. Matviienko, V. Cobus, H. Müller, J. Fortmann, A. Löcken, S. Boll, M. Rauschenberger, J. Timmermann, C. Trappe, and W. Heuten. Deriving design guidelines for ambient light systems. In *Proceedings of the 14th International Conference on Mobile and Ubiquitous Multimedia*, pages 267–277. ACM, 2015.

[20] H. Müller, J. Fortmann, M. Pielot, T. Hesselmann, B. Poppinga, W. Heuten, N. Henze, and S. Boll. Ambix: Designing ambient light information displays. In *Proceedings of Designing Interactive Lighting workshop at DIS*. Citeseer, 2012.

[21] E. D. Mynatt, J. Rowan, S. Craighill, and A. Jacobs. Digital family portraits: supporting peace of mind for extended family members. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 333–340. ACM, 2001.

[22] D. Offenhuber and S. Seitinger. Over the rainbow: information design for low-resolution urban displays. In *Proceedings of the 2nd Media Architecture Biennale Conference: World Cities*, pages 40–47. ACM, 2014.

[23] L.-C. Ou, M. R. Luo, P.-L. Sun, N.-C. Hu, and H.-S. Chen. Age effects on colour emotion, preference, and harmony. *Color Research & Application*, 37(2):92–105, 2012.

[24] E. R. Pedersen and T. Sokoler. Aroma: abstract representation of presence supporting mutual awareness. In *Proceedings of the ACM SIGCHI Conference on Human factors in computing systems*, pages 51–58. ACM, 1997.

[25] Z. Pousman and J. Stasko. A taxonomy of ambient information systems: four patterns of design. In *Proceedings of the working conference on Advanced visual interfaces*, pages 67–74. ACM, 2006.

[26] P. Rashidi and A. Mihailidis. A survey on ambient-assisted living tools for older adults. *IEEE journal of biomedical and health informatics*, 17(3):579–590, 2013.

[27] M. Tomitsch, K. Kappel, A. Lehner, and T. Grechenig. Towards a taxonomy for ambient information systems. In *Ambient Information Systems*, 2007.

[28] M. Weiser and J. S. Brown. The coming age of calm technology. In *Beyond calculation*, pages 75–85. Springer, 1997.