Deriving Design Guidelines for Ambient Light Systems

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ABSTRACT
Recent interest in the development of ambient light systems has initialized a new research area, where the number of ambient light systems is expected to increase in the next years. To support the development of future ambient light systems, we need clear, explicit, and structured design guidelines. In this paper we present an evaluation of light patterns in a controlled laboratory study with two complementary parts. In the first part, our aim was to reveal and analyze light patterns that encode different types of everyday information. In the second part, we verified the results from the first part by asking another group of participants about their understanding of information encoded with light. Together, our results allowed us to establish light patterns and guidelines for building new ambient light systems and applications in the future.

CCS Concepts
•Human-centered computing → Human computer interaction (HCI);

Author Keywords
Ambient light systems; light evaluation; design guidelines; information encoding; peripheral display.

INTRODUCTION
Weiser et al. [28] noted that calm technology is one of the challenges that ubiquitous computing brings to computing. *Calm technology* in his work is defined as a technology that unnoticeably acts in human everyday life. He also raised a problem of computers being all around us that brings up a need to rethink the goals, context and technology that crowds into our lives. Nowadays an overwhelming amount of information competes for users' attention using different modalities and information representations. One such modality that is highly used in the recent research is light [22]. Light is a versatile medium. The modification of its basic parameters (color, brightness, LED position and temporal aspects such as duration and rhythm) provides a large design space that requires substantial knowledge.

MUM '15, November 30-December 02, 2015, Linz, Austria

ISBN 978-1-4503-3605-5/15/11...$15.00
DOI: http://dx.doi.org/10.1145/2836041.2836069

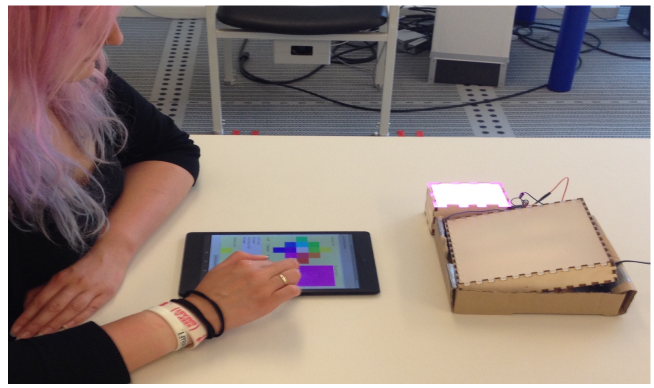


Figure 1. Participants suggest light patterns for information encoding with Android application and two Arduino prototypes.

Systems that use light to convey a piece of information on the periphery of human vision or grab a user's attention are called *ambient light systems*. We consider ambient light systems as a subclass of ambient systems that represent infromation via basic light parameters in a non-iconic way. For example, ambient light systems are used to encode a spatial information in automotive context [14], or temporal information in the office environemnt [21], [**?**]. The rising development of such systems requires guidelines to assist the design process in the future.

None of the existing design guidelines focused specifically on the light modality. This leaves designers at a loss how to develop the best solutions for presenting information with ambient light systems. To overcome this gap and find suitable guidelines we structured and collected similarities of existing light encodings. By structuring these similarities we aimed to build a fundamental categorization of ALS and, therefore, defined four information classes. These information classes are:

Progress: shows a relative indication of goal achievement by monotonously increasing or decreasing values.

Status: shows the absolute current value with possible change of tendency with no indication of goal reachability.

Spatial: shows a direction to a point-of-interest.

Notification: shows information that grabs the user's attention.

We based the design of our study on the study of Harrison et al. [10] and Laugwitz et al. [12]. Harrison et al. designed a study where participants had to map adjectives to light patterns. He defined information categories, showed participants different light behaviors and asked to classify these light patterns. As result they derived different blinking patterns for notification encoding and pulsing for a low battery state. However, the focus of this study was on the point lights. In our study we use similar approach of mapping light patterns to information classes, but in the larger scope of light patterns that involve dynamics of lights such as linear or stepwise color changes with multipe colors and LEDs. The work by Laugwitz et al. served us in the contruction of the validation study by providing the structure for the user experience questionnaire.

In order to derive design guidelines to support the future development and implementation of ambient light systems, we designed a lab study with two complementary parts. In our study we focused on color, brightness of light, and LED position. The aim of the first part was to find light patterns that encode a given list of everyday scenarios. Here, we asked participants about their interpretations and understanding of information encodings. The aim of the second part was to verify the derived light patterns from the first part with another and larger group of participants. We evaluated whether the light patterns from the first part of the study suggested by one group of participants were clear and could be unambiguously interpreted by another group of participants. Based on this, we derived design guidelines for the future development of ambient light systems. Additionally, we split the participants of the study into two age groups (under 35 and above 35) in order to observe and compare the tendencies and differences in the light pattern perception. This age separation was done due to the fact that age 35 evenly divided our sample group into two halfs.

RELATED WORK

We are interested in light patterns that combine color, brightness of light, and LED position. In the following subsections we give a short overview of ambient light systems and their light encodings. The examples listed below served as the basis for the scenrios used in the study.

Progress

Ambient Timer [21] and WaterJewel [6] use color to encode time change via a color fading from green to red. ActivMON [3] exploits color fading from red to yellow to present individual activity level. AmbiPower [19] uses color fade from green to red to show power consumption over the course of the day. Green color means low and red color means high level of electricity consumption. If the household did not use any electricity, the color would not change.

Thus, we learnt that elapsing time is encoded via color fade from green to red and none of the prototypes apply only brightness for conveying information in the information class *Progress*.

Status

Color in information class *Status* is mostly used to encode the following information: identity of a person (Damage [29]), type of an object (Public Transportation Locator [25]), distance information (AmbiCar [14], Treasure Hunt [16]), and energy consumption ("Energy Consumption Prototype" [15]). In Damage red, blue, green, and white colors refer to four different friends. Distance to the Point-of-Interest in Public Transportation Locator is shown via brightness: the closer the target, the brighter the LED. Distance to a car in AmbiCar is encoded in the following way: the car is close - LED is red, car approaches - orange, no danger - LED is off. Treasure Hunt follows the principle of color fading from purple to orange. The cold color (purple) means the user is far away and a color change towards the warm color (orange) indicates that the user is approaching the target. In "Energy Consumption Prototype" the level of consumption is displayed via a fading from green over yellow to red.

The combination of color and brightness is used to represent an assessment of physical activity (MoveLamp [7], Pediluma [13]). MoveLamp uses color in the combination with a change of brightness to represent physical activity from green (high) to red (low). Pediluma encodes physical activity with one green LED and different levels of brightness. The more the user has been walking, the brighter the LED is. The brightness increases with a rise of physical activity and dims in the opposite situation.

LED position in the combination with color is mostly used for temperature encoding. Circle [30] displays temperature using color fading and LED position on a watch. The color changes from warm (orange) to cold (blue) indicating accordingly high and low temperature.

Thus, we observed that color and brightness is the most frequent combination of light parameters to encode status information.

Spatial

Two prototypes in *Spatial* use the LED position to give an indication of a special target (AmbiGlasses [23], Rotating Compass [26]). AmbiGlasses are glasses with integrated LEDs on the frame of it and show the direction according to the position of lighted up LED. Rotating Compass has an circular arrangement of LEDs on top of the box and indicates the direction to go via LED that is on, e.g. an LED lighted up on the left indicates the user should go left. Sparkle [20], however, represents the direction an object is coming from by a corresponding LED, e.g. the LED on the left side means that an object is coming from this direction. Additionally to the change of LED position, Perception Pillar [5] and Follow the Lights [11] use different brightness levels to show user navigation instructions.

We observed a tendency that LED position is the main light parameter to encode spatial information.

Notification

Call Detector [25] visualizes an incoming call with color by projecting red and green colors on both sides of a phone:

Progress	1. Timer: Imagine there is an event in two hours. How could light inform you about the time left before this event starts? (elapsing time) 2. Goal: Imagine you are jogging and your goal is to cover the distance of 6 km. How could light inform you about the distance progress until you reach the goal? (reaching defined goal)
Status	3. Temperature: Imagine you are having breakfast and you want to know the actual temperature. How could this information be displayed with light? (higher - lower) 4. Speed: Imagine you are jogging and a light (e.g. attached on your shoe) shows you your actual speed. How could this information be displayed with light? (slower - faster) 5. Presence: How could light inform you about the current number of people in your fitness studio? (fuller - emptier) 6. Physical Activity: An ambient light shows you a valuation of your current physical activity, e.g. jogging, cycling. how could it look like? (better - worse) 7. Distance: Imagine you are going for a walk. How could light inform you about the current distance to you home? (closer - further)
Spatial	8. Direction (Turn-by-Turn): Imagine you have to display the concrete way to POI with light - how would the following directions look like: forward, backward, right, and left? 9. Direction (Compass): Imagine you have to display a direction to POI - how would the compass points look like? (North, North-East, East, South-East, South, South-West, West, North-West)
Notification	10. Urgent Notification: Imagine you have a notification about your important meeting. How could a light notify you? 11. Unimportant Notification: Imagine there are unread messages. How could a light notify you?

Table 1. User Study Scenarios.

red represents "dismiss", and green "answer". Both AuraOrb [1] and Damage [29] use an increasing brightness to alert about a new message. However, AuraOrb additionally requires a human eye contact to display more information. Circle [30] notifies about an upcoming event using blinking light. AmbientTimer [21] uses blinking red light to indicate the end of a time slot. ActivMON [3] alerts via blinking light about the physical activity of other group members. Almost all light prototypes from this information class use a combination of both color and brightness in order to display new alerts. Circle and Point [30] represent with brightness how many unread messages arrived and color represents the sender ID. LumiTouch [4] also indicates a message through brightness. But a variety of color is used for an indirect communication. The Reminder Bracelet [9] uses LED position and brightness to alert about a new notification. Each of the three LEDs indicates successively the start of the next event via a blinking light.

To sum up, different blinking patterns are used as a notification for users.

Design Guidelines

Pousman and Stasko [24] presented a classification of ambient informaiton systems with four different dimensions. Within one dimension a designer has five levels from low to high to evaluate a system. Tomitsch et al. [27] extended this classification of ambient information systems to nine following characteristics: abstraction level, transition, notification level, temporal gradient, representation, modality, source, privacy and dynamic of input. All of them are used as design dimensions.

Mankoff et al. [17] suggested a list of heuristics to support evaluation of already existing ambient systems. Brewer [2] provided another set of guidelines that support the design process of ambient systems. Both sets were presented as a list of questions that the designer has to answer before building a new system.

The focus of the existing taxonomies is not specifically on ambient light systems. Therefore, in order to fill this gap we aim to derive the design guidelines to support development of the ambient systems that use light to convey an information.

USER STUDY

We designed a study with two complementary parts to discover information encodings via light. We investigated different combinations of light color, brightness, and different positions of LEDs to derive what information can be encoded.

In the first part of our study we derived the appropriate mappings of light patterns suggested by participants in accordance to the information classes. By the term *appropriate* we mean that these light patterns should have a degree of attention arousal and aesthetic appearance, be perceptible and distinct. The selection of the scenario provided the independent variable and the number of the light pattern was the dependent variable. Additionally, we expected to be able to derive new light patterns for information classes which do not have a concise light pattern for everyday life scenarios, e.g. physical activity, event notification.

In the second part of the study we investigated whether each light pattern from the selected set of light patterns identified in the first part is suitable to represent certain information in a given scenario. Independent variable was light patterns and dependent - likert scale assessment. We wanted to check whether information encoded via light can be recognized. To do so, we showed light patterns and asked participants to map them to an existing everyday situation using Likert Scale. By this we wanted to verify that different light patterns designed in the first part are appropriate for the scenarios they were

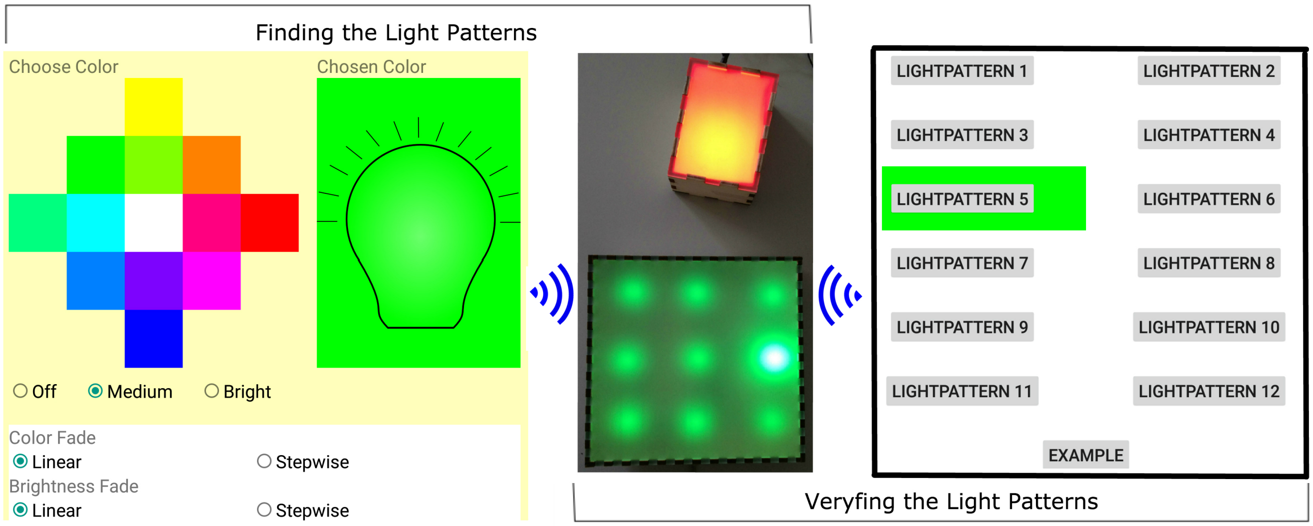


Figure 2. Android Application *Creating Light Patterns* (left), Arduino Prototypes (middle), Android application *List of Light Patterns* (right).

initially designed. An appropriateness of light patterns we measured by averaged grade from Likert Scale over all participants. Additionally, we aimed to draw generalized conclusions for the design of light patterns for generic information classes: *Progress*, *Status*, *Spatial*, and *Notification*. We also hypothesized that the perception of light patterns depends on the age.

General Procedure

Finding the Light Patterns

For the first part of the study we decided to create scenarios, which describe existing everyday situations from all four information classes. For this, we abstracted eleven scenarios from the prototypes found in the literature search (Table 1). However, in order to create generalized guidelines we did not rely on the variety of encodings used in the related work. Intead, we set up the study in a controlled environment to generate comparable patterns. Moreover, the procedure of deriving the light encoding in the related work was varying. Therefore, we unified it in the lab study to create a substantial basis for the comparison and generation of guidelines.

Participants received an Android application *Creating Light Patterns* and two generic ambient light prototypes based on Arduino hardware (Figure 2, left and middle). They were given a list of scenarios and were asked to design a light pattern for each scenario by manipulating light parameters such as color, brightness, and LED position. Therefore, they were asked to select the parameters from *Creating Light Patterns* application for each scenario that they think fit best. After selecting the preferred light parameters from the Android application and sending the data to a prototype, LEDs start glowing in the suggested way. Color, level of brightness for start/middle/end part of light pattern, and color and brightness fades were saved in the log file. All participants received the same set of scenarios and the order of the scenarios was counterbalanced. After each of the scenarios, we interviewed participants about the selected parameters (e.g. Why did you choose this color/this fade?) to gain further qualitative feedback.

Verifying the Light Patterns

In the second part of the study we used all of the light patterns derived from part one *Creating Light Patterns*. For some scenarios from the first part of the study we got the same light patterns for different scenarios. Therefore, we chose non-repetetive light patterns from the first part of the study to be verified in *Verifying the light patterns* (Table 2 - first three rows).

This time participants map a light pattern to suitable information. The order of scenarios was randomized using Latin Square. We presented the same eleven scenarios for different kinds of everyday activities to all participants. Participants used a 5-point Likert scale to indicate how well a light pattern suits to specific information. We also asked them to think aloud during this process. If participants faced mapping problems they could skip a light pattern or leave out a scenario.

Participants

We recruited 15 participants (7 female and 8 male) aged between 24 and 58 (mean 34) for the first part and another 30 participants (14 female and 16 male) aged between 18 and 86 (mean 40) for the second part of the study. In the second part of the study we aimed to cover as large age range of participants as possible to track perception differences of light between age groups. Participants in both parts of the study were originally from western countries. None of participants had vision problems, color blindness, or any other color recognition limitations.

Apparatus

For the first part of the study we programmed an Android application *Creating Light Patterns* (Figure 2, left) for a tablet that communicates via Bluetooth with two Arduino prototypes: the single-light (Figure 2, middle, upper part) and the spatial data display (Figure 2, middle, lower part). The single-light

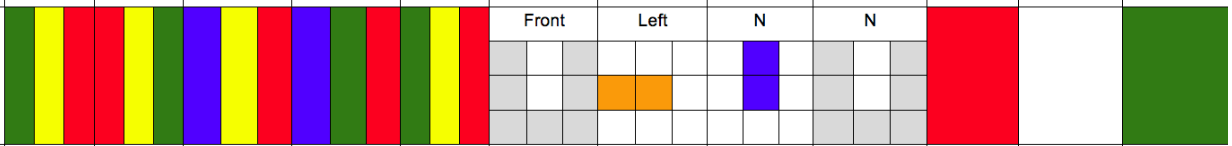
Information Class	Progress		Status			Spatial				Notification		
Name of Light Pattern	LP1	LP2	LP3	LP4	LP5	LP6	LP7	LP8	LP9	LP10	LP11	LP12
Color Encoding						Front	Left	N	N			
Full Description	Color linearly fading from green through yellow to red with linearly increasing brightness	Color linearly fading from red through yellow to green with static brightness	Color linearly fading from blue through yellow to red with static brightness	Color linearly fading from blue through green to red with static brightness	Color stepwise fading from green through yellow to red with static brightness	LEDs light up only in white color additionally to the central, but NOT diagonally	LEDs light up in different colors additionally to the central, but NOT diagonally	LEDs light up in different colors additionally to the central, including diagonal	LEDs light up only in white color additionally to the central, including diagonal	Blinking red light	Blinking white light	Blinking green light
Situations: Suit best	Timer Presence	Goal Physical Activity	Temperature	Temperature	Timer Presence	Direction (Turn-by-Turn)	Direction (Turn-by-Turn)	Direction (Compass)	Direction (Compass)	Urgent notification	Unimportant Notification	Unimportant Notification
Situations: Suit worst	Direction (Turn-by-Turn Compass)	Direction (Turn-by-Turn Compass)	Direction (Turn-by-Turn Compass)	Direction (Turn-by-Turn Compass)	Direction (Turn-by-Turn Compass)	Temperature Presence Physical Activity Notification (urgent)	Temperature	Notification (urgent, unimportant)	Temperature, Speed, Presence, Distance, Notification (urgent, unimportant)	Direction (Turn-by-Turn Compass)	Direction (Turn-by-Turn Compass)	Direction (Turn-by-Turn Compass)

Table 2. Design Guidelines.

display contains twelve Neopixels groupped together and the spatial data display contains nine Neopixels that form 3x3 matrix with 5 cm distances in-between.

Both of the prototypes are based on Arduino board and are enclosed in wooden boxes in form of a rectangular parallelepiped with different sizes (the single-light - 7x9x5cm and spatial data display - 16x16x3cm). The single-light display shows a light in different colors and brightness levels through the diffuse acrylic glass side of the box, and the spatial data display uses only one color, but different positions of LEDs to convey spatial information. With the spatial data display we wanted to give users an opportunity to suggest spatial information encoding not only with color and brightness, but also with LED position.

In the Android application *Creating Light Patterns* users specified the light parameters by setting the changes of color, brightness, and fading for initial, middle and end states. In the upper part of the screen they selected a color from the color cross, and brightness for the initial state using radio buttons. We changed the arrangement of colors from the common color circle [8] to a cross, because we wanted to make the size of white color equal to the rest without shifting the arrangement of complementary colors. The result of the chosen parameters was directly displayed on the picture on the right side ("Chosen Color") and on the prototype. Then participants selected the fading progress for color and brightness - linear or stepwise. By scrolling down an application they could select the color and brightness for the end state of LED and for the ones in between in the same way as for the initial state. Finally, participants pressed the button to send results to prototypes and the whole light pattern was displayed on the prototype.

In the second part of the study we used another Android application *List of Light Patterns* (Figure 2, right) where participants had to select one light pattern from list of twelve light patterns and send it to the same prototypes as in the first part of the study. While the light pattern was displayed on a prototype the label from the application changes its color to green (as shown on Figure 2, right) to indicate the current selection. The participant could choose a light pattern as often as it was needed by repeatedly tapping on a light pattern from the list. Additionally, participants received cards with a list of situations and Likert scale next to it in order to grade a light pattern suitability.

RESULTS

In the following subsections we present the results from both parts of the study *Finding the light patterns* and *Verifying the light patterns*. Table 2 represents design guidelines we derived using the results of our study.

Finding the light patterns

Qualitative Content Analysis

After the first part of our study we analyzed interpretations and comments of all 15 participants. We investigated and categorized them for similarities to find agree/disagree statement and count the number of participants who have similar interpretations. Number of comments or associations for some light patterns was higher than the number of participants, because some of participants mentioned the same association multiple times, e.g. green is positive. We structured the data, ran feedback loops, and categorized the interpretations of participants according to the method described by Mayring [18]. As a result we derived the following outcomes from participants.

In total 59 statements contained red with an association of negative. 46 times participants associated green as something positive. 16 statements include traffic light pattern (red/yellow/green) as the most suitable for everyday information encoding.

Regarding temperature encoding, one participant said: "For temperature I can map blue to cold and red to warm". In total 15 statements contained blue as an association with cold.

Regarding direction encoding, eleven times it was mentioned that color was not useful and six times that it was irrelevant. 21 statement included a need to encode spatial information only with LED position. Participants also mentioned that remembering many colors for encoding of different directions was overwhelming. For distance encoding eight statements contained a mapping: cold color - far away, warm color - near.

14 statements contained that the linear fade of light patterns is inherent for information class *Progress*.

Nine statements contained no need for notification when system works properly. In seven statements blinking was associated with something annoying. It was suggested two times to use light only for important notifications.

Quantitative Results

For each part of the light pattern we took color, level of brightness (2 - high/1 - middle/0 - low), and light fade (linear/steps). We analyzed all three aforementioned light parameters separately by counting the number of users' suggestions per light pattern and per part of light pattern (Start/ Middle/ End). For example, for the *Goal* situation we derived: start - red (high), middle - yellow (high), end - green (high) with linear fade of color and brightness, because for 'Start' - red color, high brightness and linear fade in general were suggested the most frequently, and so on. We had the same procedure over all participants' suggestions for all everyday situations. As a result, we derived the light patterns that encode presented situations (Table 3). All light patterns from information classes *Progress* and *Status* received a linear fade, except *Presence* situation from *Status*.

We had also exceptional situations where not only the most frequently suggested parameter was taken to the light pattern. For example, high brightness for 'Start' was the most frequently suggested for *Timer* situation. In our opinion, it was illogical to have high-middle-high brightness fade for a process that encodes an elapsing time. Therefore, we changed starting brightness to low, because low level of brightness indicates a start of the continuous process.

Verifying the light patterns

Qualitative Content Analysis

During the second part of our study we could get informative qualitative feedback from 20 out of 30 participants. Another ten participants either forgot about thinking aloud during an experiment, or were completely silent. From these 20 Participants we investigated the protocols in the same way as in the first part of the study. 72 statements include a negative association with the color red. For example, one participant said: "Red is dangerous", referring to the situation which describes

Information Class	Situation	Light Pattern: Color&Brightness			Fade
		Start	Middle	End	
Progress	Timer	Start	Middle	End	
		0	1, 1	2	Linear
	Goal	2	2	2	Linear
Status	Temperature	Cold	Middle	Warm	
		2	2, 2	2	Linear
	Speed	Slow	Middle	Fast	
		2	2	2	Linear
		2	2	2	Linear
	Presence	Empty	Middle	Full	Steps
		2	2	2	
	Physical Activity	Few	Middle	A lot	Linear
		2	2	2	
	Distance	Near	Middle	Far away	Linear
		2	2	2	
Spatial	Turn-by-Turn	Combination of light up LED in the middle with the one around it shows the direction			
	Compass				
Notification	Urgent		Blinking		
	Unimportant				

Table 3. Light Patterns.

the distance from home. Another participant mentioned "Red means I am not that good" with reference to the physical activity. About 45 statements of these 72 pertain to light patterns which contain green color in the light pattern (LP1, LP2, LP4, LP5, LP7, LP8, LP = Light Pattern). 48 times participants associated green with something positive. Further more, none of the protocols included a negative association with green. Ten times the light patterns which included green, yellow and red were associated with a traffic light.

Regarding the blue-red-gradient (LP3), none of the participants associated the color red in a negative way. Eight participants said, in this light pattern red means warm. One participant mentioned: "Now, when green is gone, this is not such a good-bad-thing anymore". In total 22 statements contain an association with the temperature for this light pattern.

Eleven participants associated the distance with the temperature, related to the children's game "Hunt the Thimble" [1].

Regarding temperature encoding, one of the participants mentioned that it was enough colors in the light pattern to encode temperature more precisely to observe stepwise change.

Concerning the light patterns which consider the position of the LEDs (LP6 - LP9), 26 statements include that these patterns remind the participants of a clock. 17 participants mentioned that the colors for LP7 and LP8 would not fit. Twelve of them said the colors are confusing or even irritating.

For LP10 - LP12 nine participants considered the blinking too obtrusive. Five of them suggested a pulsing instead.

Regarding the transition between the colors, four participants said that the stepwise change would give a better impression when a state changes, but they would not exactly know how far their status would proceed. In contrast, eight participants

[1] https://en.wikipedia.org/wiki/Hunt_the_Thimble

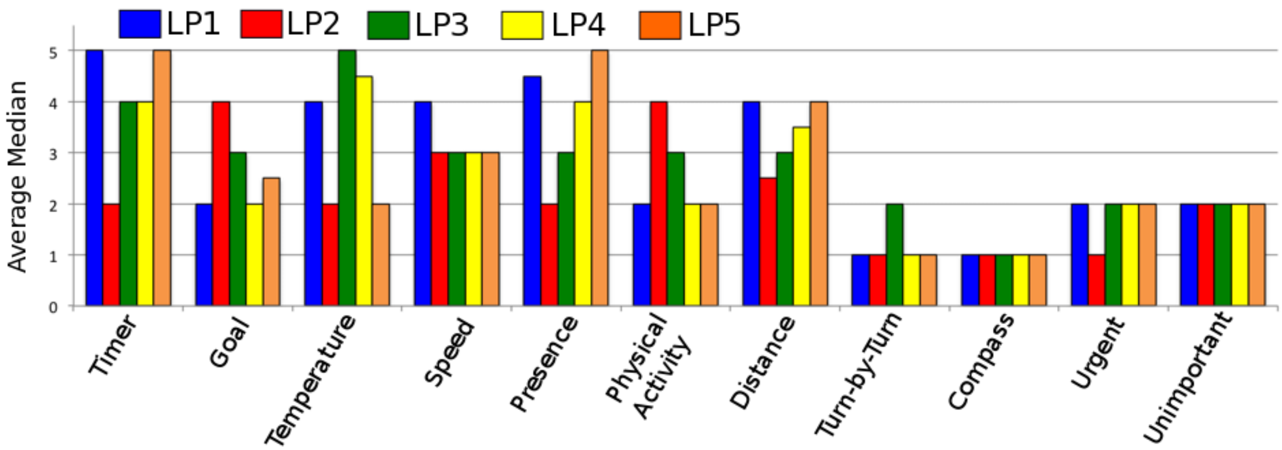


Figure 3. Progress&Status.

mentioned that a linear transition enables a "rough estimation" the whole time.

Quantitative Results

We grouped the quantitative results of the study according to the information classes in order to underline the pecularities of these information classes: *Progress* & *Status* (LP1-LP5) (Figure 3), *Spatial* (LP6-LP9) (Figure 4, 5), and *Notification* (LP10-LP12) (Figure 6). As an exception, we analyzed information classes *Progress* and *Status* in one subsection, because information that belong to these information classes is similarly encoded.

To encode the answers of participants from Likert Scale questionnaire we used 5-point Likert scale, where 1 - strongly disagree and 5 - strongly agree. On the figures in following subsections we show, however, a scale from 0 to 5 to highlight a better visual comparison.

We have done the group and pairwise comparison of the light patterns within information classes per each everyday situation. By this, we derived light patterns that suit better and worse for a particular everyday situation (Table 2). Tables 4 and 5 contain the statistical results. All post hoc analyzes were conducted with a Bonferroni correction to avoid type I errors.

Age groups

The grades for LP1-LP5 for both younger and elder groups are similar with a small difference in medians. For information class *Sptial*, however, there were significant differences between *Turn-by-turn* and *Compass* for four position LED light display without color ($Z = -2.703$, $p = 0.007$) and with color ($Z = -3.211$, $p = 0.001$) and no significant difference between *Turn-by-turn* and *Compass* direction for eight position LED light display without color ($Z = -0.820$, $p = 0.412$). Both age groups graded LP8 in the same way (median 4). Younger and elder age groups graded LP9 as the most suitable for situations *Turn-by-turn* (median 3 and 4) and *Compass* (median 4 and 5) with the difference in median.

As for information class *Notification*, both age groups perceived LP10 as the most suitable for *Urgent* notification and the least suitable for *Unimportant* notification. LP11 for elder group had the same grades (median 3) for both *Urgent* and *Unimportant* notifications, while younger group graded LP11 with median 4 for *Urgent* and median 4.5 for *Unimportant* notification. Elder group graded LP12 higher for *Urgent* notification (median 4) than younger (median 3), while younger group graded LP12 higher (median 4) than elder group (median 2) for *Unimportant* notification.

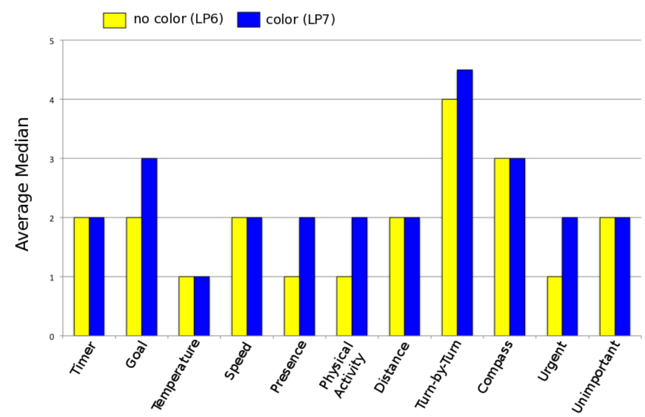


Figure 4. Spatial: four positions

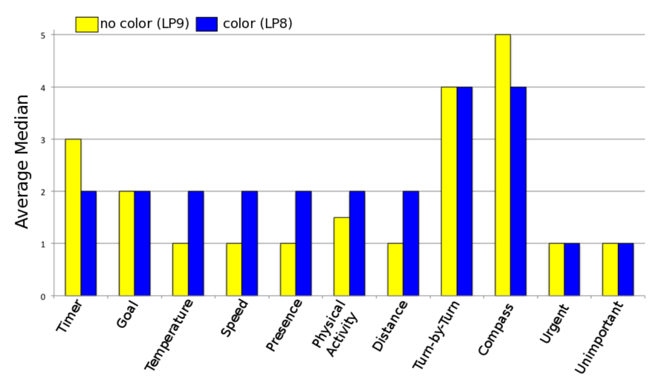


Figure 5. Spatial: eight positions

	Progress				Status									
Everyday Situation	Timer		Goal		Temperature		Speed	Presence		Physical Activity		Distance		
Friedman test	$\chi^2(4)=21.3$ $p<0.001$		$\chi^2(4)=27.8$ $p<0.001$		$\chi^2(4)=41.3$ $p<0.001$		$\chi^2(4)=0.8$ $p<0.939$	$\chi^2(4)=33.7$ $p<0.001$		$\chi^2(4)=20.4$ $p<0.001$		$\chi^2(4)=16.1$ $p=0.003$		
Post hoc test with Wilcoxon signed-rank		LP1		LP3		LP4			LP1		LP3		LP4	LP5
	LP3	Z = 2.225 p = **0.026**												
	LP4	Z = 2.939 p = **0.003**	LP2	Z = -3.596 p = **0.001**	LP1	Z = -2.803 p = **0.005**		LP4	Z = -3.334 p < **0.001**	LP2	Z = -3.231 p < **0.001**	LP1	Z = -1.883 p = **0.06**	Z = -1.761 p = **0.078**
	LP5	Z = -1.694 p = **0.09**			LP3	Z = -0.319 p = **0.75**		LP5	Z = -0.878 p = **0.38**			LP5	Z = -0.737 p = **0.461**	

Table 4. Summary of Statistics: Progress & Status.

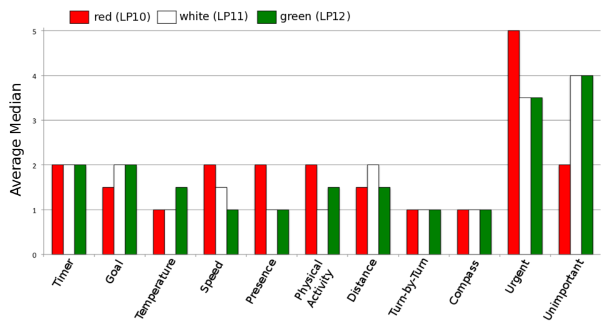


Figure 6. Notification

DISCUSSION

Study Limitations

We conducted a lab study with a perception of LED light and its parameters. Different arrangement of LEDs, form factor of devices, and social affordances can change the light perception. However, our aim was to conduct a fundamental study about light encoding. Thus, we used the same wooden boxes in *Verifying the light patterns* as in the initial *Finding the light patterns*. As far as our participants were Europeans, our results might not be extended to the light encoding paradigms in the other parts of the world.

Encoding Information Classes

Progress & Status. The first important outcome for information classes *Progress* and *Status* lays in the fact that perception of red color highly depends on whether it is shown in the combination with green or blue (GL1).

Red light is often perceived as something negative, but only when green color is present in the pattern. For example, in case of LP1 and LP5 with a color fade from green to red, red is perceived as 'no time' (LP1) and 'no place' (LP5). Green in these light patterns indicates that everything is alright. 'Negative' and 'dangerous' characteristics of red light are better distinguishable and perceptible in the contrast to green color.

In contrast to LP1 and LP5, LP2 has a fade of color from red to green. LP2 received the highest Likert assessment for *Goal* and *Physical Activity* situations. For most of participants reaching the established goal is positive (green), and being in the very beginning is negative (red). As for *Physical Activity*, most of the participants described green color as 'good' and 'more active', and red as 'bad' and 'less active'.

We also explain the high grades for LP1-LP5 from the elder group of participants for situation *Goal* by the absence of the clear color mapping to the beginning and the start of the process. Thus, any linear or stepwise fade of one color to another can be used for *Goal* encoding for elder people.

For *Distance* and *Speed* we did not derive the most suitable light patterns. However, medians (Figure 3) indicate the tendencies with a support of qualitative results that fast driving or jogging is often associated with green color, and being slow - with red color.

On the other hand, red is perceived as warm in contrast to blue, and not anymore as something negative, when there is no green color present in the light pattern. LP3 and LP4 were graded as the most suitable for temperature encoding, where blue indicates low temperature. Combination of red and blue colors also suits for encoding of *Distance*. In this case the mapping is the following: warm color means near to POI, and cold color - far away.

The second important outcome for information classes *Progress* and *Status* is that colors of initial and end states play the main role in light patterns with a fade from one color to another (GL2). For example, light patterns LP3 and LP4 are rather similar with only difference in the middle color. The purpose of leaving these two similar light patterns in the study was to investigate whether the presence of more colors and, therefore, a smoother change from cold to warm color plays a significant role. Our quantitative results show that there is no significant difference. The middle color (in our case green and yellow) is less important for information encoding than color of start and end states.

As the third important outcome we state that one of the main differences between information classes *Progress* and *Status* lays in the color fade (GL3). Linear fade is common for *Progress* and stepwise for *Status*. To evaluate the distinction between these information classes, we compared two light patterns (LP1 and LP5) with the same colors, but different fades. LP1 has a linear color fade with linearly increasing brightness, while LP5 has a stepwise color fade with a static brightness. We could not directly prove this difference with *Verifying the light patterns*, because we evaluated the light patterns that had only one direction of change. It means there was a change

	Spatial				Notification					
Everyday Situation	Turn-by-turn		Compass		Urgent			Unimportant		
Friedman test	$\chi^2(11)=107$ $p < 0.001$		$\chi^2(11)=111.7$ $p < 0.001$		$\chi^2(11) = 123.2$ $p < 0.001$			$\chi^2(11) = 72.8$ $p < 0.001$		
Post hoc test with Wilcoxon signed-rank		LP7		LP9		LP11	LP12		LP11	LP12
					LP10	Z = -3.907 **p<0.001**	Z = -4.181 **p<0.001**	LP10	Z = -2.825 p = **0.005**	Z = -2.76 p = **0.006**
	LP6	Z = - 0.218 p = **0.827**	LP8	Z = -1.51 p = **0.132**	LP11		Z = -1.276 p = **0.202**	LP11		Z = -1.117 p = **0.264**

Table 5. Summary of Statistics: Spatial & Notification.

from green to red, but no change from red to green back within one light pattern. However, quantitative and qualitative results from *Finding the light patterns* explicitly state that linear fade of color is common for *Progress* information class. Information from *Progress* does not need to be exact and explicitly specified, because an approximation of progress is already enough. On the other hand, the exact current state for *Status* is much more important in order to visualize temperature, speed, or distance. The presence of steps in the fade brings a clear distinction between the states.

The fourth important outcome for information classes *Progress* and *Status* is the frequent usage of traffic light colors mapping for the assessment of everyday situations (GL4). Following the traffic light approach, yellow is usually perceived as signal to prepare, or as an indication of being in the middle of the process. Red is bad, negative, alarming, stopping and green is good, positive, neutral, permissive. The combination of red/yellow/green is also one of the most frequently suggested color combinations in *Finding the light patterns*.

Spatial. Based on our findings, the most important outcome for *Spatial* is the absence of difference for direction encoding with or without colors (GL5). For most of participants colors did not provide any information and were perceived as irrelevant. For some participants colors were misleading and confusing.

As expected, light patterns with four positions were the most suitable for encoding of *Turn-by-Turn* direction, and with eight position for *Compass* direction (GL6). Brightness also did not play a crucial role. The most important light parameter for direction encoding is LED position. Brightness, however, can be used as an addition for distance encoding, and color for a type of POI or ID. Color also can be set up in accordance to the personal preferences of users.

In *Finding the light patterns* participants did not choose many colors for spatial information encoding. They explained it by an unwillingness to remember many colors that encode different kinds of objects or directions. In the same part of the study we asked participants the meaning of their own encodings for information from *Spatial*. Some of participants had difficulties to recall the encodings. We conclude that overwhelming amount of different light encodings brings overload of users and, therefore, decreases an efficiency of usage.

Notification. The first important outcome for the information class *Notification* is the best suitability of red blinking light for urgent notification (Figure 6) (GL7). In this situation red color is perceived as something alarming, and not as warm or something negative. Red blinking light (LP10) has the highest grade for urgent information encoding and is significantly different from the white and green blinking light. Some of participants also suggested to vary the frequency of blinking to encode different levels of urgency. They suggested to use higher frequency of blinking for urgent situations and lower frequency of blinking for unimportant notification. In our study we excluded light patterns with different levels of blinking and used only color as an indication of notification type, because our main focus was on basic changes of color, brightness, and LED position. By basic changes of brightness we mean increase and decrease. However, we aim to evaluate light patterns with different levels of pulsing and blinking in the future work.

The second important outcome for the information class *Notification* is indifference of light color for unimportant notifications (GL8). From quantitative results, we derived that white (LP11) and green (LP12) blinking light is the most suitable for unimportant notification encoding. Moreover, white and green blinking patterns are not significantly different from each other (Figure 6). Thus, we conclude that color does not play a role for unimportant notification, except for red color, which indicates an urgent notification. Some of participants also mentioned that the presence of blinking light or light in general for unimportant notification is rather irrelevant. The elder group, however, perceive both red and green blinking light as something urgent (GL9).

Design Guidelines

Based on the results of our study and the discussion above, we derived the following design guidelines (GL) for ambient light systems:

GL1: When red and green colors are used in combination, red is perceived as negative and green as positive, but not when they are used separately.

GL2: The middle color of a fade is not crucial, but the colors of initial and end states are.

GL3: For *Progress* a linear color fade is the most suitable, whereas for *Status* it is stepwise.

GL4: Usage of traffic light colors is the most frequently suggested light combination for assessment of everyday situations.

GL5: Color is unimportant for spatial information encoding.

GL6: 4-position light pattern is the most suitable for turn-by-turn and 8-position - for compass information encoding.

GL7: Red blinking light is the most suitable light pattern for urgent notification encoding.

GL8: Color is unimportant for non-urgent notification encoding.

GL9: Elderly persons perceive colored blinking light as an urgent notification.

The derived guidelines can be used in the variety of application domains. For example, in the systems that display physical activity of the user during some time period. Using GL1 and GL2 a designer uses red color to indicate low and green for high physical activity with a focus on the initial and end states. Another example is a system that reminds elderly persons to take medication. With GL9 a designer focuses on the blinking light pattern as a reminder with a variation of color.

CONCLUSION & FUTURE WORK

In this paper, we investigated light patterns from the study with two complementary parts about light encoding of everyday information, and derived design guidelines for ambient light systems.

We contribute to existing design knowledge of ambient light systems by providing a list of design guidelines that should be taken into consideration during light information encoding. The focus of these guidelines is on color, brightness, their fading, and LED position. We additionally derived guidelines that indicate which light patterns are most and least suitable for particular scenarios. By this we ease the design and development process of future ambient light systems. We also support the definitions and peculiarities of the information classes we defined: *Progress*, *Status*, *Spatial*, and *Notification*. We claim that these information classes provide a good classification for ambient light systems and simplifies the work on ambient light systems. This covers the whole design space of existing ambient light systems, where any such system can be assigned to these classes.

Future work will explore the usage of light patterns in certain application domains, such as automotive, physical activity, and office. In these domains we additionally plan to test light patterns with different variations of light parameters. Furthermore, we aim to derive clear guidelines by which to evaluate ambient light systems.

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