Real-Life Experiences with an Adaptive Light Bracelet

Jutta Fortmann
University of Oldenburg
Oldenburg, Germany
jutta.fortmann@uni-oldenburg.de

Benjamin Poppinga
Smarttention Systems
Oldenburg, Germany
bp@benjaminpoppinga.de

Wilko Heuten
OFFIS - Institute for Information Technology
Oldenburg, Germany
heuten@offis.de

Susanne Boll
University of Oldenburg
Oldenburg, Germany
susanne.boll@uni-oldenburg.de

ABSTRACT

In the last years, wearable devices have been an emerging trend on the market. Today, several wearable devices present information through light spots, especially those used for self-tracking. In this work we present a field evaluation of an adaptive light bracelet that serves as a reminder of fluid intake. We investigated how users and observers experience the bracelet under real-world conditions in comparison to a non-adaptive bracelet. Context awareness is implemented in that the LED's brightness changes according to an ongoing event. In a 16-participant 2-weeks experiment we found participants and observers experienced the adaptive bracelet more positively. Further, we found observers experienced the adaptive bracelet significantly more attractively and could identify significantly better with it. Our results will inspire designers and developers of wearable light displays.

CCS Concepts

•Human-centered computing → Empirical studies in ubiquitous and mobile computing;

Keywords

Wearable Computing, Digital Jewellery, Fluid Intake Reminder, Light, Context Awareness, Observer Experience

1. INTRODUCTION

In recent years wearable devices have been an emerging trend on the market. Devices that promote a healthy lifestyle have become especially popular. To use all a device's capabilities, a person needs to wear it all the time, thus, aesthetics, as well as physical and social comfort, are important aspects of the device. Typically, wearables are shaped in a convenient way, such as clips or wristbands. To visualise information, many devices use small displays, e.g., to show the number of steps taken, such as the Fitbit One[1]. Other devices, such as the Nike+ FuelBand[2], use light emitting diodes (LEDs), e.g., to indicate the progress towards a set goal. While the information is important for the users themselves, it can cause discomfort and can confuse bystanders when displayed in a conspicuous way. Consequently, the unobtrusiveness of a persuasive device has been identified as an important design goal [3].

At the same time, it is unclear how this design goal can be achieved. Context awareness has generally been proposed as a possible solution [10, 15]. However, this has not yet been studied for wearable light displays in real contexts, which makes its impact questionable. In this paper, we present a field study, in which we evaluated an adaptive light bracelet that serves as a fluid intake reminder. The bracelet consists of one permanently illuminated Reminder LED, eight Volume LEDs, and a button. We enable users to change the bracelet's appearance, i.e., the brightness of the Reminder LED, according to an ongoing calendar event. The ongoing calendar event defines the context to which the brightness of the LED adapts. We studied how the adaptive display will change the bracelet's usability, and how users and observers perceive the adaptive bracelet with regard to emotions, attractiveness, and identity in comparison to a non-adaptive version of the bracelet.

We found that participants experienced the adaptive bracelet as being significantly more *stylish*, *presentable*, and *pleasant*. Observers felt significantly happier when looking at an adaptive bracelet than when looking at a non-adaptive bracelet. Also, observers could identify significantly better with the adaptive bracelet and found it significantly more attractive than a non-adaptive bracelet.

The contributions of this paper are as follows:

- We present a wearable adaptive fluid intake reminder display, a light bracelet that implements context awareness by connecting the LED's brightness level to calendar events.
- We show that participants and observers experienced the adaptive bracelet more positively than a non-adaptive

British HCI 2015, July 13 - 17, 2015, Lincoln, United Kingdom

ISBN 978-1-4503-3643-7/15/07...$15.00

DOI: http://dx.doi.org/10.1145/2783446.2783572

[1] https://www.fitbit.com/uk/one

[2] http://www.nike.com/us/en_us/lp/nikeplus-fuelband

bracelet, by conducting and analysing a 2-weeks field study

The paper is structured as follows. After we give insights into related papers and key research findings, we describe the adaptive light bracelet. We then present a field study, in which we investigated the effect of context awareness on *emotions*, *attractiveness* of the display, and *identification* with the bracelet. After discussing our findings, we conclude the paper with a summary of insights, the key contributions and ideas for future work.

2. RELATED WORK

In the following we present related work which focuses on wrist-worn light displays, and wearable context-aware systems.

2.1 Wrist-Worn Light Displays

In previous work different applications have been proposed for wrist-worn light displays. Hansson et al. [7] proposed the Reminder Bracelet, a simple black bracelet with three red LEDs, which indicated notifications triggered by a connected PDA. Its purpose was to notify the user of scheduled events in a subtle and silent way using light, colour and blinking patterns. Damage was another, more fashioned LED bracelet consisting of one white and five coloured LEDs. The author's vision was to connect it to a messenger application on a smartphone for that it supports the communication in a social group [16]. Ahde and Mikkonen [1] describe their vision of communicating spatial proximity of friends by using LED-illuminated bracelets. With ActivMON, Burns et al. [2] presented a watch-like device with an LED that shows the user's and the user's friends' physical activity level. Today's wearable consumer products such as the Fitbit Flex[3], the Nike+ FuelBand, or the Misfit Shine[4] use single light spots to present information in a simple and quickly accessible way.

2.2 Context-Aware Systems

Context awareness is an important feature of a wearable user interface [10, 5, 15]. Dey [4] defines context as

> "[...] any information that can be used to characterise the situation of an entity [...], that is considered relevant to the interaction between a user and an application.".

Furthermore, he defines that

> "a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task.".

Dey lists three categories of features that a context-aware application can support, which are:

- presentation of information and services to a user,
- automatic execution of a service for a user, and
- tagging of context to information to support later retrieval.

[3]https://www.fitbit.com/uk/flex

[4]http://www.misfitwearables.com/

In his list of four ideal attributes of a wearable device, Starner [15] defines that a wearable device must observe the user's environment to provide the best cognitive support for the user. A wearable device should adapt its interaction modalities based on the user's context, and it should augment and mediate interactions with the user's environment.

In previous work, several context-aware wearable displays have been presented. Rhodes [12] introduced the Wearable Remembrance Agent, a system with a heads-up display that provides notes to the user that might be of relevance at a certain moment. The captured context information is e.g. the time-stamp, the user's physical location, and which persons are around. Kern and Schiele [10] investigated whether or not to notify the user in a specific context and if so, through which modality. They classified the context according to five factors: the importance of the event that is being notified (a), the user's activity (b), the social activity (c), the social situation (d), and the location (e). They present a model to classify typical situations with regard to the interruptability of the user and that of the environment. Also, they map these interruptability classes to appropriate notification modalities, which are vibration, beep, ring, speech message, a watch display, and a head mounted display.

Our system uses light to present information. Light as a modality to present information can be modified in various parameters. From the perception oriented colour model HSV (Hue, Saturation, Value) we can derive the basic parameters of light: colour, saturation and brightness [14]. These parameters can be extended with regard to time and space. Time can be expressed in the duration for which a light is presented. Furthermore, when manipulating the parameters it is possible to create various rhythms with varying colours, saturations and brightness. Space can be expressed in the spatial location of a presented light. Previous work on wearable light displays found that the light's brightness has a big influence on the perceived obtrusiveness of the display [2, 11]. In this work, we use the light's brightness to regulate the obtrusiveness of the display dependent on the event the user is currently taking part in.

Previous work investigated which kind of information should be presented [12], in which level of detail information should be presented [13], and through which modality an information should be presented in a specific context [10]. As a light display has a much higher visibility than a graphical display, its presentation design is important. This especially applies to wearable displays worn in a mobile context in which other people are close by. However, it has not been studied yet how information should be presented on a wearable light display in a way that fits well into everyday life. From previous work, we know that the context in which a wearable display is worn changes the degree of comfort a wearer feels [6]. Thus, we need to investigate if and how such displays should adapt to the context to make the wearer feel more comfortable.

3. THE ADAPTIVE LIGHT BRACELET

For the study, we expanded WaterJewel, a fluid intake reminder bracelet [6], by context awareness capabilities. WaterJewel is implemented on the Arduino platform and uses light spots to present information on a user's fluid intake behaviour. The conceptual design is based on a recommendation of the European Food Safety Authority to drink at least 2 litres of fluid a day in 8 evenly distributed servings.

A continuously illuminated light spot reminds the user to drink regularly in that it indicates the time elapsed since the last intake ("Reminder LED"). This is presented by a gradient from red (user drank two or more hours ago) to green (user just drank). Another eight LEDs are arranged in a row and show the amount of fluid intake for the day, i.e. how many glasses have been drunk ("Volume Display"). The first seven LEDs are coloured blue. The last one is green to highlight that the daily goal of 8 servings of fluid has been accomplished. A drink entry is made though a long push of a button on the bracelet. The Volume Display is activated through a short button push.

For the study, the WaterJewel bracelet was accompanied by an Android application that connects to the bracelet via Bluetooth. After an initial pairing the application automatically connects to the bracelet whenever it is in reach. This application is able to control the brightness of the Reminder LED at three different levels, which can be mapped directly to certain obtrusiveness levels as follows:

Level #1 switched off – unobtrusive

Level #2 low brightness – less obtrusive

Level #3 full brightness (default) – obtrusive

Instead of using a custom user interface, we linked the application to the device's calendar. This allows users to specify the brightness (obtrusiveness) of the Reminder LED in the title of a calendar entry, e.g., *Tea-Time with Granny #2*, thereby making the bracelet adaptive to individual calendar entries. Here, a calendar event defines the context. When a new calendar event starts, the brightness of the Reminder LED is updated immediately according to the digit placed after the hash mark in the event's title. When there is no calendar event defined in the user's calendar application, the LED's brightness will be set to the default value, i.e., the brightest level.

4. FIELD EVALUATION METHOD

An earlier study of WaterJewel and related work found that a light's brightness has a major influence on the perceived obtrusiveness of a display [6, 5, 11]. However, how exactly a display should adapt brightness in practice, and how in detail an adaptation changes the human's perception of the display, remains unclear. In this study, we adopt the idea to modulate the display's brightness and study how an adaptive Reminder LED changes the overall perception of the bracelet. In detail, we investigated how users as well as observers experienced the bracelet in everyday situations in terms of perceived emotions, identification with the bracelet, and perceived attractiveness of the bracelet. In detail, we investigate the following hypotheses:

H1 An adaptive display positively affects the perceived *emotions* when confronted with the bracelet.

H2 An adaptive display positively influences how people *identify* with the bracelet.

H3 An adaptive display positively changes the perceived *attractiveness* of the bracelet.

Because our goal was to study the adaptation on a wearable device, we studied the hypotheses from two perspectives. On the one hand, we studied each hypothesis for the participants of our study, i.e. the wearers of the device, which we refer to as **H1P**, **H2P**, and **H3P**. On the other hand, we investigated the hypotheses for the external observers of the system, which we refer to as hypotheses **H1O**, **H2O**, and **H3O**.

4.1 Participant Questionnaire

To measure the *emotions* (**H1P**), the *identity* (**H2P**), and the *attractiveness* (**H3P**), we decided for subjective feedback through a custom questionnaire. This questionnaire is supposed to be answered in-situ and while or just after actually using the bracelet. Therefore, it first asks for details about the situation, i.e., date, time, place, lighting conditions, and the type of persons who accompany the participant, e.g., the public, family members, or nobody. Further, the participant was asked if he or she perceived the brightness of the Reminder LED during the situation as suitable on a 7-point Likert scale, ranging from *disagree* (1) to *agree* (7). As measures for emotions, identity, and attractiveness, we integrated parts of two established standard questionnaires, i.e., Differential Emotions Scale (DES) [9] and AttrakDiff [8], into the questionnaire. The part that was inspired by the DES consists of a set of 8 statements about emotions, e.g., *"I felt surprised"*, and could be rated on a 7-point Likert scale, ranging from *disagree* (1) to *agree* (7). We chose the DES because we were especially interested in the emotions perceived towards the bracelet, and the DES is a validated instrument to assess these. The AttrakDiff alone would not have covered emotions extensively. Further, the questionnaire comes with 13 contrary word pairs, e.g., *isolating/connecting*, which were taken from the AttrakDiff questionnaire and measure the hedonic quality and attractiveness of a used device. In detail, 6 of these pairs measure the *identity* (HQ-I), and 7 of these pairs measure the *attractiveness* (ATT). The attributes from the AttrakDiff are rated on a 7-point scale ranging from the first word (1) to the second word (7). A full list statements and word pairs can be found in Table 1.

4.2 Observer Questionnaire

With the participant questionnaire we measure how an adaptive bracelet changes the emotions of a participant, i.e. the wearer of the bracelet, how he or she identifies with the bracelet, and how it attracts him or her. However, to get a holistic understanding, we also studied how these three aspects change for observers. The aspects need to be studied to provide answers to hypotheses **H1O**, **H2O**, and **H3O**. An observer is a person that stays in the proximity of the wearer by accident. The duration of an observation can vary.

Observers completed the same questionnaire as an online version with further details, such as a study participant identifier and a unique, alphanumeric nickname, which the observer could freely decide on. These values allowed mapping all questionnaire responses. Observers could be made aware of the online questionnaire through a study participant, who was wearing the bracelet. The awareness could be created using a *link card*, which is a paper card that comes with instructions, a written link as well as a QR code to the online questionnaire, and the unique, numeric identifier of the study participant who handed the card (see Figure 1, top).

4.3 Design

We designed the study as a within-subjects, repeated measures experiment with two conditions. One condition is the

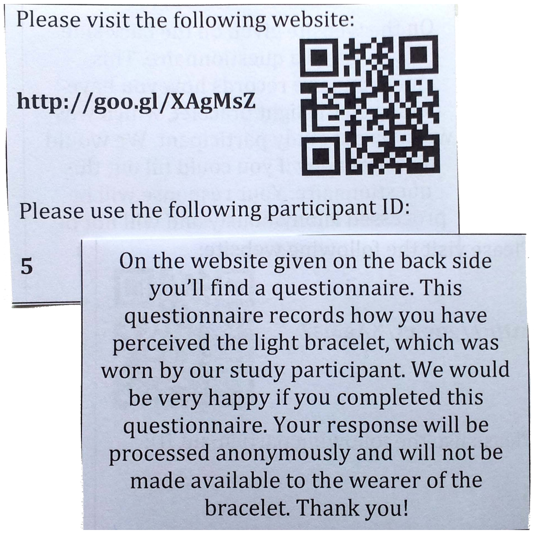

Figure 1: Observers were provided with link cards that come with a link to an online questionnaire (top). These allow to capture the observer's experiences and impressions regarding the bracelet. Link cards were originally provided in German.

earlier described light bracelet with adaptiveness, i.e., the brightness of the Reminder LED can be controlled. The other condition is the light bracelet without any adaptation features, i.e., the default brightness is used. We counterbalanced the conditions. Thus, half of the participants started with an adaptive, the other half with a non-adaptive bracelet.

4.4 Participants

We acquired 18 participants, of which 2 stopped their participation after a few days for personal reasons. The remaining 16 participants had an average age of 26.1 years (SD 3.79 years), ranging from 20 to 37 years. 8 of the participants were male, and 8 were female. They were recruited from the local university, and through public announcements. None of the participants was related to the research team. Participants had an average daily fluid intake of about 1.5 liters (SD 0.50 liter), ranging from less than 1 liter to 3 liters. 12 participants reported that they want to increase their fluid intake, 3 were undecided, and 1 participant reported no interest in increasing fluid intake.

4.5 Procedure

At the beginning of the study, participants signed an informed consent and completed a demographic questionnaire. We introduced and set up the light bracelet with the corresponding application on the participantsâĂŸ smartphones, and they got some time to become familiar with the system. Also, we explained how participants could specify the brightness of the Reminder LED when entering a new calendar event in their favourite calendar application.

Participants were handed 40 of the earlier described paper questionnaires and 40 of the link cards. We asked the participants to complete approximately three of the questionnaires per day and after varying situations, e.g., after a business meeting or after taking the metro. Further, we asked participants to hand out approximately three of the link cards per day. These should be handed to observers, i.e. colleagues, friends, or any other persons who experienced any kind of situation together with the study participant wearing the light bracelet.

Figure 2: Male participant wearing the light bracelet during the study. On his upper arm he wears an additional armlet that contains the controlling hardware, which is whipped with black felt for aesthetic reasons.

Each participant used the light bracelet for a total of two weeks during his or her daily routine. Figure 2 shows a male participant wearing the light bracelet during the study. Half of the participants started with an adaptive bracelet, i.e. the brightness of the Reminder LED could be controlled. The other half started with a bracelet that had no adaptation features, i.e. the default brightness was used. After the first week, the condition changed for all participants. During the study, we conducted two interviews with each participant, one after each week. We asked for overall impressions and went through the completed questionnaires participants brought with them, so that they could elaborate on striking situations. Furthermore, participants completed the well-established System Usability Scale (SUS) after each week. After the second interview we collected all handed materials, supported participants in deleting the app that controlled the light bracelet, clarified on remaining questions, and thanked the participants. Each participant was rewarded with 25 EUR.

5. QUANTITATIVE RESULTS

In the following, we report our key quantitative findings, whereby a full representation of the results can be found in Table 1. For both, i.e., participants who wore the bracelet and observers, we will report on changes in emotions, identity, and attractiveness. We used one-sided Wilcoxon signed rank tests for all statistical investigations, because we expected only positive effects of the context awareness.

5.1 Participant

Of the 640 handed questionnaires (40 questionnaires for each of the 16 users), 416 (65.00 %) were completed and returned. Of these, 218 were completed when using the bracelet in the control condition and 198 when using it in the experimental condition, in which it provided context awareness. 97 questionnaires were answered for situations in which participants were alone, 62 when they were in pub-

	Statement	Participant Contr.	Participant Exp.	Participant Sign.	Observer Contr.	Observer Exp.	Observer Sign.
Differential Emotion Scale	I felt happy.	3.43	3.45	n.s.	3.62	4.69	0.01
	I felt surprised.	2.24	2.24	n.s.	4.15	5.31	n.s.
	I was annoyed.	2.13	2.13	n.s.	1.54	1.56	n.s.
	I was ashamed.	1.42	1.40	n.s.	1.15	1.31	n.s.
	I felt guilty.	1.26	1.21	n.s.	1.00	1.44	n.s.
	I was feared.	1.12	1.08	n.s.	1.00	1.19	n.s.
	I was interested.	3.11	2.82	n.s.	5.39	6.00	n.s.
	I was sad.	1.12	1.07	n.s.	1.08	1.31	n.s.
AttrakDiff, HQ-I	isolating/connective	4.03	4.13	n.s.	3.92	5.00	0.01
	tacky/stylish	3.17	3.42	0.05	2.85	4.00	0.05
	cheap/premium	3.35	3.43	n.s.	3.23	4.25	0.05
	alienating/integrating	3.99	4.06	n.s.	3.92	4.94	0.01
	separates me/brings me closer	4.01	4.11	n.s.	3.92	5.19	0.01
	unpresentable/presentable	3.48	3.71	0.05	3.00	3.75	n.s.
	average	3.67	3.81	n.s.	3.47	4.52	0.01
AttrakDiff, ATT	unpleasant/pleasant	3.38	3.58	0.05	3.31	4.44	0.05
	ugly/attractive	2.95	3.21	n.s.	2.85	3.63	n.s.
	disagreeable/likeable	3.73	3.90	n.s.	4.08	5.13	0.05
	rejecting/inviting	3.97	4.01	n.s.	3.92	4.75	0.05
	bad/good	4.11	4.23	n.s.	4.46	5.38	0.05
	repelling/appealing	3.77	3.86	n.s.	3.85	4.75	0.05
	discouraging/motivating	4.56	4.45	n.s.	4.31	5.38	0.05
	average	3.78	3.89	n.s.	3.82	4.77	0.01

Table 1: An overview of all quantitative observations for participants and observers. Ratings on the Differential Emotion Scale were given on a 7-point Likert scale, ranging from *disagree* (1) to *agree* (7). Responses to AttrakDiff pairs ranged from the first word (1) to the second word (7).

lic among strangers, 59 when they were with friends, 57 when they were with family, 9 when they were with colleagues, 4 when supervisors were present, and in 4 cases the participants did not provide us with details about the situation. The remaining 124 questionnaires were answered in combinations of the above-mentioned situations, mostly when participants were moving in public, accompanied by family or partners. According to the free text answers about the place, most participants stated they used the bracelet at home or at work.

In the questionnaires, participants were asked to assess the appropriateness of the Reminder LED's brightness. In the control condition, i.e., without context awareness, participants rated the appropriateness with 4.82 (SD 1.35). In contrast, participants rated the appropriateness with 5.90 (SD 1.08) in the experimental condition, i.e., about a full step better. This difference is significant ($p < 0.01$).

We asked participants to assess their emotions in the experienced situations, using a set of statements which were inspired by the Differential Emotion Scale (DES). Overall, they mostly stated similar emotion ratings for both conditions. The most notable difference between the conditions was observed for the rated interestedness, where the control-condition was rated with 3.11 (SD 1.48) and the experimental condition with 2.82 (SD 1.64). However, this and none of the other emotion statements showed any statistical significance.

The questionnaires further assessed how the participants identified with the bracelet, which was measured with the HQ-I part of the AttrakDiff questionnaire. On average, the HQ-I was 3.67 (SD 0.86) in the control condition and 3.81 (SD 0.95) in the experimental condition (see Figure 3). This difference is of no statistical significance. However, we observed that participants assessed the display as being more stylish in the experimental condition (M 3.42, SD 1.03) than in the control condition (M 3.17, SD 0.99). Further, participants assessed that the experimental bracelet was more presentable (M 3.71, SD 1.36) than the non-adaptive bracelet (M 3.48, SD 1.26). Both of these observations are of statistical significance ($p < 0.05$).

As a third parameter, the questionnaire assessed the perceived attractiveness of the system, which was measured with the ATT part of the AttrakDiff questionnaire. Overall, participants tend to agree that the bracelet is similarly attractive in both conditions, i.e., experimental 3.89 (SD 1.06), control 3.78 (SD 1.05). In detail, we found that participants rated the experimental system as significantly ($p < 0.05$) more pleasant to use (M 3.58, SD 1.60) than the non-adaptive system (M 3.38, SD 1.64, see Figure 3).

After each week, participants were asked to complete a System Usability Scale (SUS) questionnaire. We observed that in the control condition the light bracelet was rated with 80.63 (SD 13.65), whereby it was rated with 79.22 (SD 17.74) in the experimental condition. This difference is not significant.

5.2 Observer

Altogether, the study participants issued 152 link cards to observers, 82 during the experimental condition and 70 while using the bracelet in the control condition. On average, each participant issued 5.13 (SD 2.78) link cards in the experimental and 4.34 (SD 3.48) in the control condition. 27 observers considered the link cards and completed a total of 29 online questionnaires, which results in a 19.08 %

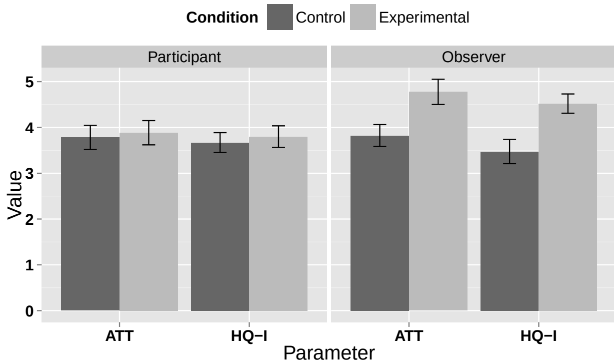

Figure 3: For study participants we were unable to observe any significant differences regarding identity (HQ-I) and attractiveness (ATT). In contrast, we found significant effects for the attractiveness and identification observers perceived towards the bracelet. Error bars indicate the standard error.

return rate. Of these observers, 11 classified themselves as friends of the study participant, 5 as strangers, 4 as family members, 4 as colleagues, and 3 as professional superiors. 16 completed questionnaires concerned participants who were using the light bracelet in the experimental condition, 13 responses were assessing participants who used it in the control condition.

We found that observers felt significantly happier when facing an adaptive bracelet (M 4.69, SD 0.87) than facing the regular bracelet (M 3.62, SD 1.50, $p < 0.01$). Otherwise we did not observe any statistically significant changes in perceived emotions.

Regarding the identification of observers with the system, i.e., HQ-I, we observed that they overall tend to agree more in the experimental condition (M 4.52, SD 0.84) than in the control condition (M 3.47, SD 0.96, see Figure 3). This difference is statistically significant ($p < 0.01$). In detail, we found that observers rated the experimental system to be more connective (control 3.92, SD 0.95; experimental 5.00, SD 0.73; $p < 0.01$), more stylish (control 2.85, SD 1.34; experimental 4.00, SD 1.51; $p < 0.05$), more premium (control 3.23, SD 1.64; experimental 4.25, SD 1.19; $p < 0.05$), more integrating (control 3.92, SD 0.76; experimental 4.94, SD 0.77; $p < 0.01$), and less separating (control 3.92, SD 1.04; experimental 5.19, SD 0.98; $p < 0.01$).

We further found that the attractiveness (ATT) of the bracelet changes significantly, depending on whether it is adaptive or not. For the control condition observers agreed to the attractiveness with 3.82 (SD 0.86) on average, whereby they agreed with 4.77 (SD 1.10) in the experimental condition (see Figure 3). This difference is statistically significant ($p < 0.01$). In detail, the experimental condition was rated to be more pleasant (control 3.31, SD 1.32; experimental 4.44, SD 1.21, $p < 0.05$), likeable (control 4.08, SD 1.32; experimental 5.13, SD 1.45, $p < 0.05$), inviting (control 3.92, SD 0.95; experimental 4.75, SD 1.39, $p < 0.05$), good (control 4.46, SD 1.20; experimental 5.38, SD 1.26, $p < 0.05$), appealing (control 3.85, SD 0.90; experimental 4.75, SD 1.24, $p < 0.05$), and motivating (control 4.31, SD 0.75; experimental 5.38, SD 1.54, $p < 0.05$).

6. QUALITATIVE INSIGHTS

In the following we describe the qualitative insights that we gained from the interviews with the participants. For the analysis, interview notes were coded jointly by the interviewer and the study director.

6.1 Overall Impressions

Overall, most participants liked the idea and the concept of the bracelets. Several participants mentioned they received positive feedback from friends, who said they would also like to use the bracelet as a fluid intake reminder. In general, ten participants would like to use the bracelet in future, with some saying it would have to be more sophisticated (P11, P03), more compact (P02) and pretty (P06). Four participants said they would not need it because they found they already drink enough. Two participants would prefer an app to a bracelet. Three participants stated they found the app annoying in the way that they had to check if the Bluetooth connection was available once in a while and in that they had to interact with the phone to, e.g., enter dates. Five participants mentioned they would have preferred to regulate the display's brightness directly with a button on the bracelet instead of with the app.

When we asked the participants for situations in which they would not wear the bracelet, they named various situations for different reasons. They stated situations in which the bracelet could be damaged, such as during sport activities, housework, in bed or when sweating due to hot temperatures. They also named situations such as festive occasions, burials, being onstage, at work and in a job interview, because in these situations the bracelet would not match the clothes and appearance. With regard to the condition in which the bracelet was not adaptive, a participant mentioned he felt uncomfortable wearing the bracelet at the dentist because it lighted brightly. Regarding the same condition, another participant reported that a lecturer wanted him to remove the bracelet during a talk.

6.2 Perception of the Different Brightness Levels

Most of the participants said they in general appreciated the mapping of the different obtrusiveness levels to the different brightness levels. But, the preferences for particular brightness levels varied. In situations in which the brightness level was set to the brightest level #3, some participants complained about the light being too bright, in particular in dimmed or dark environments. Participant P06 explicitly said that he did not like that he could not switch off the display during the non-adaptive condition. However, with respect to brightness level #1, which meant the light was off, two participants said they did use it very rarely or never at all, because they disliked that the bracelet did not provide any feedback. Participant P10 found that brightness level #2 was the best choice in many cases. Another participant said he would be fine with brightness level #3 only. Two participants wished for one or to more levels, e.g., between brightness level #1 and #2 (P08).

6.3 Perceived Difference Between the Conditions

Nine participants stated they did not consciously perceive a difference in the bracelet's display between the first and the second study week. Five participants said they consciously perceived a difference and appreciated that the brightness of the display could be adapted in the experimental condition. In the experimental condition two participants mentioned that, after a while, they got used to the bracelet and did not notice that they were wearing it.

6.4 Impact on Fluid Intake Behaviour

After the study, 10 participants stated they drank more during the study than before. Two participants said they drank much more consciously. Another two participants felt confirmed by the bracelet in that it showed them they drink enough. During the study, situations occurred in which participants did not feel the display to be necessary. For example, a participant reported that during lunch he did not need the display because he drank anyway. However, drinking behaviour was not tracked in the study because it was not in the focus of this research. Effects on fluid intake behaviour have been investigated in previous work [6].

7. DISCUSSION

The results show that participants, who wore the bracelet, and observers differed in their perception of the adaptive bracelet. Overall, participants rated the adaptive and the non-adaptive bracelet similarly. In the three ratings *stylish*, *presentable* and *pleasant* they rated the adaptive bracelet slightly higher. The ratings of observers were more marked. They rated the adaptive bracelet more positively than the non-adaptive bracelet in many aspects. Observers felt happier when facing an adaptive bracelet. In general, they could identify significantly better with the adaptive bracelet and found it to be significantly more attractive than the non-adaptive bracelet.

7.1 Adaptation in General

Overall, participants liked the idea and concept of the bracelets. In general, they appreciated the mapping of obtrusiveness levels to brightness levels, but their preferences for particular brightness levels varied. Some participants reported that in the beginning they could hardly estimate how they should adjust the brightness levels, but after experiencing the light in situ it was much easier.

Five participants wished for a manual regulation of the bracelet's brightness directly on the bracelet. This shows that it is important that the device can be adapted to different contexts, but the adaptation does not necessarily need to happen automatically. During the study, situations occurred in which participants felt that the display of information was not necessary, e.g., while having lunch. This indicates that adaptation should not only be considered in terms of the presentation design, but also in terms of the information content that is presented. This implication fits in well with Starner's fourth ideal attribute of a wearable device: "Augment and mediate interactions with the user's environment" [15].

7.2 Emotional Responses

We recorded the emotional responses to the bracelet from participants, i.e., wearers, and from observers, who were confronted with the participants and the bracelet in various situations. Our observations indicate that context awareness and the related brightness adaptation do not change the emotional responses significantly. Therefore, we have to reject **H1P** and **H1O**, and cannot argue that an adaptive light display improves perceived emotions for wearers or observers.

In the interviews, five participants said they appreciated that the brightness of the display could be adapted in the experimental condition. This indicates a positive emotional change towards the adaptive bracelet from the subjective view of at least five participants. We suppose that the set of statements we used according to the DES could be the reason for why the emotion ratings differed from the personal statements of participants. Of the eight emotions asked for, six were phrased negatively and only two positively, and the emotions were very hard. When comparing user interfaces that differ only slightly in particular aspects, the emotions asked for might not change significantly. Also, assessing the DES-oriented emotions in general might be difficult when evaluating a product because they focus on emotions we typically do not connect to products, such as being "feared" or "sad". Other emotions are not covered at all, e.g., the emotion described by "I appreciate that.", which participants stated in the interviews, cannot be mapped to one of the emotions we asked for in the DES-oriented questionnaire.

7.3 Identification With and Attractiveness of the Bracelet

The issued questionnaire comes with a section to measure to what extent participants identify with the system. Further, another section measures the perceived attractiveness of the system while being worn by participants. Both sections were taken from the popular and established AttrakDiff questionnaire [8]. Our findings indicate that there are no measurable significant differences in the identification with and attractiveness of the system, therefore we have to reject **H2P** and **H3P**.

Nevertheless, 5 of 16 study participants stated that they clearly noticed the difference between the default brightness and adapted brightness. Consensus was that the adaptation is highly appreciated and valued, particularly for sensitive situations, where the default brightness could be perceived as disturbing or distracting. The quantitative results indicate that participants found the adaptive bracelet significantly more stylish and more presentable. Therefore, we suggest to further research the effect of adaptation on the perceived attractiveness and identity.

7.4 Observers' Perception of the Bracelet

In the study we investigated the bracelet from two perspectives: participants, who were actual wearers, and observers. We did this because earlier work in related fields showed that the perception of and reaction to wearable, interactive devices might differ significantly between these two groups.

We also asked observers to assess their identification with and the attractiveness of the bracelet with the same questionnaire that we handed over to study participants. Our results indicate that observers can identify with the bracelet significantly better in the experimental condition, i.e., when the bracelet is adaptive. Further, we found that an adaptive bracelet was assessed to be significantly more attractive to the observers. Consequently, we have to accept hypotheses **H2O** and **H3O**.

Overall, we can support the finding that wearers and observers of a device can get a different impression from a wearable device. On average, we did not observe a significant difference in HQ-I, i.e., identity, or ATT, i.e., attractiveness, for participants. However, we did find a significant difference for observers ($p < 0.01$). While the ratings between observers and participants are similar for the control condition, the observers seem to perceive the adaptation in a much more intense way, leading to a significant change in the perceived attractiveness and identity (see Figure 3).

We have the impression that observers are much more sensitive to minor changes, like the adaptation of an LED's brightness. We further think that their feelings and insights notably contribute to the overall acceptance and success of wearable technology, and that this aspect has been underevaluated in the last few years. In fact, few details are known how exactly the observers' impressions drive their reactions, and how these reactions influence and change the participants' feelings. We therefore suggest that observers and the observer's perspective should become an essential aspect of future design processes and research.

8. CONCLUSION

In the last years wearable devices that present information through simple light displays have been an emerging trend on the market. Characteristic for these displays is that they are worn in varying contexts and clearly visible by wearers and bystanders. Thus, while the presented information is crucial for a user, it can cause discomfort and confuse bystanders when displayed in a conspicuous way. However, it has not been researched yet how the displays should be designed in order to meet this design challenge.

In this paper, we presented a field study of an adaptive light bracelet that serves as a fluid intake reminder. The study elaborated on the aspect, that users perceived the lights' brightness as too obtrusive in certain situations, which was learned from previous studies. In the study, 16 participants wore the bracelet in their everyday life for a total of two weeks each. In one week the bracelet adapted the brightness of the light according to an ongoing event. In the other week the bracelet did not provide adaptiveness and always presented the light in the same brightness level.

Our results show that overall, participants liked the bracelets and the possibility to adapt the light's brightness. We found participants did not significantly perceive the adaptive bracelet differently with regard to *emotions*, *attractiveness* and *identification*, apart from single ratings, i.e., they experienced the adaptive bracelet as being significantly more *stylish*, *presentable* and *pleasant*. The ratings of observers were more marked. They felt significantly happier when facing the adaptive bracelet, could in general identify significantly better with it and found it to be in general significantly more attractive than the non-adaptive bracelet.

From the study results we conclude, that, in general, integrating context awareness into wrist-worn light displays is a promising way to improve emotions towards the display, perceived *attractiveness* of the display, and *identification* with it. The adaptation of the lights' brightness level to user-preset values has shown to be experienced as positive by participants and in particular by observers. Our results will inspire designers and developers of wrist-worn light displays and - if implemented - will add to a higher acceptance of the displays by users and observers. We assume users will feel more comfortable using a light display in everyday life, observers will be less confused and less distracted, and that finally, this will increase the time lapse for which people use the wearable display.

From our experiences we conclude that it is worthwhile to include observers in the design process and evaluation of wearable user interfaces because they can have different experiences than the actual users. Integrating both perspectives is particularly important when designing wearable interfaces as they are pervasive and thus influence all people in proximity.

In future work, we will integrate another button on the bracelet that allows to manually regulate the light's brightness, independently from the automatic brightness adaptation. To improve automatic brightness adaptation, we are interested in investigating in which situations users tend to manually regulate the brightness, e.g., by measuring lighting conditions and location information. Furthermore, we want to investigate how the brightness level should adapt when it depends on both, lighting conditions as well as calendar events. Further, we will reduce user input in that we will search calendar event titles for certain keywords, so that the brightness level mapping can happen automatically.

9. REFERENCES

[1] Ahde, P., and Mikkonen, J. Hello: Bracelets communicating nearby presence of friends. In *Proceedings of PDC '08*, Indiana University (2008), 324–325.

[2] Burns, P., Lueg, C., and Berkovsky, S. Activmon: Encouraging physical activity through ambient social awareness. In *Proceedings of CHI EA '12*, ACM (2012), 2363–2368.

[3] Consolvo, S., McDonald, D. W., and Landay, J. A. Theory-driven design strategies for technologies that support behavior change in everyday life. In *Proceedings of CHI '09*, ACM (2009), 405–414.

[4] Dey, A. K. Understanding and using context. *Personal Ubiquitous Computing 5*, 1 (Jan. 2001), 4–7.

[5] Dey, A. K., Salber, D., Abowd, G. D., and Futakawa, M. The conference assistant: Combining context-awareness with wearable computing. In *Proceedings of ISWC '99*, IEEE Computer Society (1999), 21–28.

[6] Fortmann, J., Cobus, V., Heuten, W., and Boll, S. Waterjewel: Design and evaluation of a bracelet to promote a better drinking behaviour. In *Proceedings of MUM '14*, ACM (2014), 58–67.

[7] Hansson, R., and Ljungstrand, P. The reminder bracelet: subtle notification cues for mobile devices. In *Proceedings of CHI EA '00*, ACM (2000), 323–324.

[8] Hassenzahl, M., Burmester, M., and Koller, F. AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität. In *Mensch & Computer 2003*, vol. 57. Vieweg+Teubner Verlag, 2003, 187–196.

[9] Izard, C. E., Dougheny, F. E., Bloxom, B. M., and Kotsch, N. E. The differential emotions scale: A method of measuring the subjective experience of discrete emotions. Tech. rep., Nashville: Vanderbilt University, Department of Psychology, 1974.

[10] Kern, N., and Schiele, B. Context-aware notification for wearable computing. In *Proceedings of ISWC '03*, ISWC '03, IEEE Computer Society (2003), 223–230.

[11] Lim, B. Y., Shick, A., Harrison, C., and Hudson, S. E. Pediluma: Motivating physical activity through contextual information and social influence. In *Proceedings of TEI '11*, ACM (2011), 173–180.

[12] Rhodes, B. The wearable remembrance agent: A system for augmented memory. *Personal Technologies 1*, 4 (1997), 218–224.

[13] Sawhney, N., and Schmandt, C. Nomadic radio: Speech and audio interaction for contextual messaging in nomadic environments. *ACM Trans. Comput.-Hum. Interact. 7*, 3 (Sept. 2000), 353–383.

[14] Smith, A. R. Color gamut transform pairs. In *Proceedings of SIGGRAPH '78*, ACM (1978), 12–19.

[15] Starner, T. The challenges of wearable computing: Part 1. *IEEE Micro 21*, 4 (July 2001), 44–52.

[16] Williams, A., Farnham, S., and Counts, S. Exploring wearable ambient displays for social awareness. In *Proceedings of CHI EA '06*, ACM (2006), 1529–1534.