Tangible Apps Bracelet: Designing Modular Wrist-Worn Digital Jewellery for Multiple Purposes

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ABSTRACT
Most of today's wearable devices mainly focus on functionality and show large deficits in aesthetics and comfort. However, researchers and market analysts emphasise the importance of aesthetics for wearable technology to be successful. *Smart Digital Jewellery* has been proposed as an approach to seamlessly integrate technology into appealing, body-worn objects. In this work, we investigated how a smart digital multi-purpose bracelet should be designed in order to be attractive, functional, easily comprehensible, and easy to manage. We built the *Tangible Apps Bracelet* and evaluated it in a lab study. The *Tangible Apps Bracelet* integrates multiple applications in form of single elements that are threaded on a string. Participants experienced it very positively, easy to interact with, and rated its usability and user experience as very good. They particularly appreciated its simple interaction and display concept and the seamless integration of applications and digital components into an aesthetic piece of jewellery.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces

Author Keywords
Smart Digital Jewellery; Modular Bracelet; Wearable Computing; Participatory Design, Light; Vibration

INTRODUCTION
Wearable devices, especially wrist-worn devices have become very popular [19]. Forecasts say that in 2015 the wearable market will grow approximately 173%, i.e. 72.1 million wearable devices will be shipped, from which 65.7 million units are expected to belong to wristwear [5].

Researchers state that people will not wear wearable devices that do not address their aspirational and style needs [4, 2]. Market researchers assume that a large share of the market remains untapped because of design limitations [21, 4]. *Smart Digital Jewellery* has been proposed as an approach to seamlessly integrate technology into appealing, body-worn objects [16]. Researchers proposed several concepts for single-purpose *Smart Digital Jewellery* [22, 1, 13, 6]. But, typically people demand for more than one application [7], e.g., they would like to be reminded about appointments, contact someone and at the same time keep track of their physical activity level. Three different pieces of *Smart Digital Jewellery* could solve their needs. However, this solution would result in an unmanageable amount of objects that need to be carried. Also, the space on a human's body is limited, and aesthetical and comfort issues might conflict with wearing several objects at the same time. Multi-purpose *Smart Digital Jewellery* could be a solution, but to date it is underexplored.

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Figure 1. The *Tangible Apps Bracelet* consists of single elements - each offering a specific application - that are attached to a charm bracelet. Information is presented discreetly through light and vibration.

Having a look at current jewellery trends, we see modular, customisable bracelets are in vogue. They consist of single links that are hooked on a bracelet and can be composed individually.

In this work, we investigated how a smart digital multi-purpose bracelet should be designed in order to be attractive, functional, easily comprehensible, and easy to manage. This includes its appearance, functionality, information presentation and interaction design. On the basis of a participatory design process we designed and built a modular smart digital bracelet that integrates multiple applications in form of "Tangible Apps". We evaluated the bracelet prototype in a lab study with 20 participants and assessed user experience and usability. Overall, the *Tangible Apps Bracelet* was perceived very positively, easy to interact with, and received very good usability and user experience ratings. Participants appreciated the seamless integration of applications and digital components into an aesthetic piece of jewellery and were highly willing to use the *Tangible Apps Bracelet* if it was refined into a product. From the design process and study results we derive recommendations for designing multi-purpose Smart Digital Jewellery.

The contributions of this paper are as follows:

- We present the *Tangible Apps Bracelet*, a proof of concept that illustrates how to integrate several applications into a single, aesthetic piece of jewellery.
- We show, participants of a lab study experienced the *Tangible Apps Bracelet* very positively, and could easily comprehend and handle several applications on a single piece of jewellery.
- We derive suggestions for the design of multi-purpose Smart Digital Jewellery.

The paper is structured as follows. After we give insights into related work, we present the requirements, and describe the design and implementation of the *Tangible Apps Bracelet*. We then present a lab study, in which we investigated the bracelet's user experience and usability. After discussing our findings, we conclude with a summary of insights, the key contributions and ideas for future work.

BACKGROUND AND RELATED WORK

Smart Digital Jewellery describes adornment artefacts (jewellery) that appear as jewellery and function as computational devices (digital) with a specific purpose (smart). Miner coined the early term *Digital Jewellery* that he described as: "It starts with aesthetically appealing jewellery design and forces the technology to subtly blend in or disappear." [16].

Several concepts for wrist-worn *Smart Digital Jewellery* have been proposed in research. They range from holistic concepts consisting of different pieces of jewellery, such as the wearable mobile phone, where each item implements a specific function [16], to specific pieces of jewellery, such as bracelets, that are used for, e.g., non-verbal communication [22, 1, 13] or to support daily health practices [6]. Typically, these bracelets use light or vibration or a combination of both as output modalities. Some bracelet concepts make use of exchangeable elements that are mapped to single contacts [1, 13]. Companies have created *Smart Digital Jewellery* consumer products, e.g., fitness tracker like the Misfit Shine[1], which consists of a core element that can be attached to a wristband, necklace, or clothes. The sun protection bracelet Netatmo June[2] integrates UV sensors in a metal element, and uses a smartphone app as display. Further products have been announced recently, e.g., Cuff[3], a modular jewellery concept where various pieces of jewellery can be enhanced by an emergency alert and call notification feature.

While researchers proposed several concepts for single-purpose *Smart Digital Jewellery* [22, 1, 13, 6], multi-purpose *Smart Digital Jewellery* is underexplored. Xu et al. explored how multi-purpose smartwatches could display information on, e.g., time keeping, messaging, phone calls, calendar reminders, and fitness tracking through simple light spots and backlit icons [23]. Wrist-worn multi-purpose devices, such as smartwatches[4], and smartbands[5] have become popular. Typically these devices include small screens and offer features such as, e.g., notification, displaying text messages, reminder, alarm clock, and fitness tracking. However, besides their wearability, they have not much in common with *Smart Digital Jewellery*, but are more a small wrist-worn and screen-based computer.

Having a look at the jewellery market, we see modular, customisable bracelets are in vogue. The so-called charm bracelets consist of single links that are hooked on each other[6], hooked on a bracelet[7], or threaded on a bracelet[8] (see Figure 2). The modular concept of these bracelets allows customisation through the integration of miscellaneous elements.

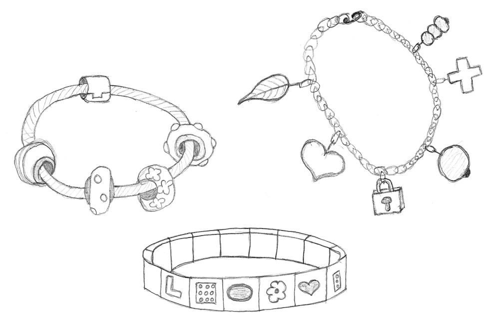

Figure 2. Charm bracelet concepts. From left to right: Links are threaded on a bracelet, hooked on each other, or hooked on a bracelet.

Smart Digital Jewellery seems to be a promising approach to create everyday suitable and long-desired computational wearable objects. Researchers have proposed various concepts for smart digital bracelets that serve single purposes, such as non-verbal communication, or healthy lifestyle support. However, with regard to the increased demand for multi-purpose devices, we need to explore the design of *Smart Digital Jewellery* that integrates various features. So far, we lack an understanding of how to design multi-purpose *Smart Digital Jewellery*.

REQUIREMENTS ANALYSIS

To define the context of use and gather the requirements for the modular bracelet, we had a look at general requirements that we gathered from literature, and conducted interviews with jewellers and potential users. All statements reflect the views of Europeans.

General Requirements

When designing *Smart Digital Jewellery*, certain requirements have to be considered that we gathered from literature on general requirements for wearable computers and *Smart Digital*

[1] http://misfit.com/products/shine
[2] https://www.junebynetatmo.com/
[3] https://cuff.io/
[4] http://www.sonymobile.com/de/products/smartwear/smartwatch-3-swr50/
[5] http://www.microsoft.com/microsoft-band/
[6] http://www.nomination.uk/composable_bracelet
[7] http://www.thomassabo.com/GB/en_GB/charmclub/charm-club
[8] http://www.pandora.net/de-de/explore/products/bracelets

Jewellery. A wearable computer has to be mobile and unrestrictive, must not occupy the user's attention, its output medium should be constantly perceptible by the user, it has to be controllable by the user at any time, it should be attentive to the environment, it could be used as a communications medium, it should be always on, and it should be personal [15, 20]. It must be comfortable and unobtrusive to wear [8, 14]. As a piece of jewellery, its appearance is crucial, i.e. it should fit to the user's clothing and jewellery fashion [17]. Previous work found that the wrist is among the most suitable and most popular body locations for a wearable computer and for jewellery [10, 18]. From Fortmann et al. we know that a quick operation, a long battery life, a good appearance, high wearing comfort, a solid and lightweight construction, and the integration of several features into one object, are the most important requirements for a Smart Digital Jewel [7].

Interviews with Jewellers

According to a semi-structured interview, we interviewed three local jewellers about the target group of bracelets, their expectations towards jewellery, and general trends in jewellery design. We found that the target group for bracelets is in general 70% females and 30% males with an age between approximately 20 to 50 years. Modular bracelets are generally only worn by women between 20 to 35 years. Customers expect jewellery to last for life and to be wearable at any occasion. It should be made of high-quality materials. Younger women like eye-catching designs and prefer silver and red gold, whereas older women prefer classical designs made of yellow gold or white gold. Men prefer bracelets to be made of leather or high-grade steel. In general, jewellery with many gemstones and made of red gold has been a trend for a couple of years. Modular bracelets have been a long-lasting trend.

Interviews with Potential Users

On the basis of the statements of the jewellers, we selected participants from the target group for semi-structured interviews. We interviewed 12 persons, including more females than males and more 20-35 years old than others. 9 females and 3 males between 17-47 years (M 28.8, SD 9.7) volunteered for the interviews. They were recruited from the local university and through public announcements. Participants were not paid for taking part. We asked participants about their interest in jewellery, and their expectations on the design and applications of a modular bracelet. To give them an idea on modular bracelet designs, we showed them pictures of current products. We motivated the integration of electronics in a way that they may not change the appearance of the piece of jewellery. We asked participants to imagine the bracelets could, e.g., blink, vibrate or play sounds and that technically everything was possible.

None of the participants owned a digital bracelet. 6 out of 9 female participants owned a modular bracelet, but none of the male participants. Participants preferred a total of 3-6 applications per bracelet. The most preferred applications were non-verbal communication (N 12), reminder (N 8), and pedometer (N 7). An element should represent an application (N 12). Female participants preferred elements to be threaded on a string and moveable (N 10). In contrast, male participants preferred the elements to be hooked on each other, so they have a fixed arrangement (N 3). Elements should be distinguished by motif, colour, and shape. Female participants emphasised the importance of different element designs because, only when looking different, they could satisfy the passion for collecting that many women tend to. Input should be made via a push button on an element. Gestures were considered to be too susceptible to misentries and too silly when performed. The preferred output modalities were light (N 11), vibration (N 10) and sound (N 10), whereas for sound participants were concerned about that it could disturb in certain situations, and only considered it to display very important information. The colour of the light should be customisable, e.g., regarding the communication application, each contact could be indicated through a certain light colour. An invisible mode should be offered to deactivate all displays of the bracelet for a certain period. In general, information should be displayed discreetly and the display should not draw the attention of persons in proximity to itself. Participants preferred to decide about the applications of an element when purchased. A single element could either offer various output modalities or each element could implement a specific output modality. The configuration could be done by means of a smartphone application. All participants stated they would wear a modular digital bracelet and would appreciate its additional value compared to an ordinary bracelet. The appearance of the bracelet would be the determining factor.

In the following list we summarise the requirements for a modular digital bracelet that we gathered beyond those already known from literature research, i.e. from the user interviews.

Functionality

- Bracelet offers between 3 to 6 applications
- Implemented applications are non-verbal communication, reminder, and pedometer
- Non-verbal communication application allows the contact making between user and specific persons through simple predefined messages like "I am thinking of you."
- Reminder application allows to set reminders for and be informed about preset events
- Pedometer application allows to display the user's current physical activity status

Aesthetics

- An application is implemented by an element
- Information is displayed discreetly
- Elements are threaded on a string

General Use and Interaction

- Bracelet can easily be put on and off
- Bracelet switches off when not worn
- Bracelet offers an invisible mode that deactivates all displays on the bracelet
- Input is made through the push of a button, e.g., for making contact
- Light and vibration are used for output, e.g., to make the user aware of someone making contact

DESIGN

On the basis of the gathered requirements, we developed designs for a modular digital bracelet. To stimulate the design process with the experiences and viewpoints of both, HCI researchers and potential users, we conducted a quick and dirty prototyping workshop [12] with participants from both groups. In a quick and dirty prototyping workshop, participants use all kind of everyday materials to built lo-fi prototypes, possible shapes or interactions. The materials include, e.g., paper, chenille wire, modelling material, handicraft materials, lego bricks, cable fixer, toothpicks, straws and sponges (see Figure 3).

Figure 3. During the quick and dirty prototyping workshop. Various materials were provided to build lo-fi prototypes.

Participants

The workshop was conducted in *Oldenburg, Germany*. Six participants volunteered for the workshop. These included three potential users, i.e. female university students between 21 to 26 years, and three HCI researchers from our lab (2 males) with an overall HCI working experience of three to six years and experience in wearable computing. None of the participants was paid for participation.

Procedure

After participants introduced themselves, we presented the idea of a modular digital bracelet and the results of the requirements analysis. We explained the three applications non-verbal communication, reminder, and pedometer. We described the preferred input and output modalities and the requirements regarding the shape of the bracelet. We also asked if participants wanted to add anything. Then, we introduced the quick and dirty prototyping method. After the introduction, participants were asked to split into groups as they wanted. We had one group of three (two female students, one male HCI researcher) and three single persons. We asked participants to consider the requirements when building prototypes. During the workshop participants communicated and discussed ideas. After the prototyping session, participants explained their prototypes. Further, we presented a lo-fi prototype that we created before the study and collected feedback from the participants.

Results

During the prototyping workshop, four different prototype designs were created and one design from the research team was presented and discussed. All designs implement the concept of “Tangible Apps”, i.e. an application (app) is implemented by a (tangible) element.

Design Concept A

Design concept A (see Figure 4) was created by a female HCI researcher and consists of three single straps that form the bracelet. The basic bracelet consists of one strap that includes a core element which can vibrate and offers a button to (de-)activate the invisible mode. This element is arranged next to the clasp. Further straps can be added and threaded in the core element. Each strap realises an application. The maximum number of applications is limited to three. With regard to the non-verbal communication application, an element on the associated strap represents a certain contact, whereas elements are distinguished by colour and shape. When someone is making contact the associated element lights up. Additionally, the core element vibrates to indicate the contacting. To initiate a contact making, the user can push the associated element like a button. On the reminder strap, each element represents a

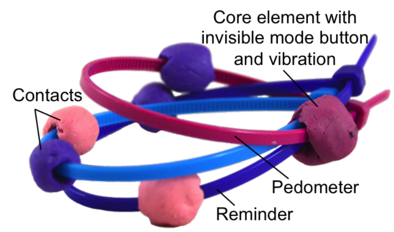

Figure 4. Design Concept A

reminder for a certain event. The associated element lights up to indicate that a reminder event is due. To display their daily activity progress, the user pushes the element on the pedometer strap. The whole pedometer strap lights up in a colour of the gradient red (little progress) to green (big progress), until the user pushes the element again. Steps are not counted by the bracelet itself, but, e.g., by an external pedometer clip or a smartphone application. The reason given was that pedometers attached to the wrist do not measure adequately. Straps in different colours should be offered for customisation. With an associated smartphone application light colours could be configured and calendar events could automatically be read and mapped to reminder elements.

Design Concept B

In design concept B (see Figure 5), which was created by two female students and a male HCI researcher, elements have different shapes to identify certain contacts, e.g., a heart and a star. To initiate a contact making, the user can push a transparent button on the associated element. If someone is making contact, the associated element lights up and the light shines through the button. The colour of the light does not encode information, but should be configurable. As with design A, an additional vibration signal should be triggered to indicate the contacting. The reminder element is completely transparent and flashes when an event is due. Through a push button on top the user can deactivate the flashing when she took notice of it. The pedometer consists of two elements that are linked through a hanging chain. When the user pushes a

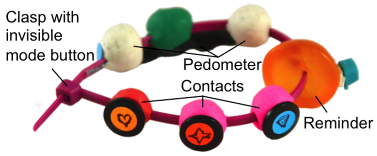

Figure 5. Design Concept B

button on one of the pedometer elements, the chain lights up in a colour of the gradient red (little progress) to green (big progress) to show the activity progress. A button is integrated into the clasp of the bracelet to (de-)activate the invisible mode. Apart from functional elements, decorative elements can be attached to the bracelet.

Design Concept C

Design concept C (see Figure 6) was created by a male HCI researcher. All elements have a very similar look and texture, can light up and additionally also vibrate. Contact elements consist of a circular area that flashes when the user is being contacted. Contacts are distinguished by the colour of the flashing light. An option would be to provide contact elements with differently shaped areas, not only circles, to simplify the mapping. The creator of this design also introduced the idea to integrate a picture of a contact person in some kind of hinged amulet. Though, it might be inconvenient that the amulet has to be opened before the user knows who has contacted her. In contrast, if no shutter would cover the picture, this might be discomforting. Each element has a button on the side that faces the hand like with common watches. To initiate a contact making, the user can push the button on the associated element. A reminder element consists of an area that is shaped as an icon that the user associates with the reminder event, e.g., a leaf illuminated in green reminds to water the plants. Either reminder elements could come with lighting areas in different shapes or the icon of the element could be exchangeable. Besides many predefined shapes, individual shapes that can be designed freely are desirable. Like with the display of contact making, the lighting area on a reminder element flashes when a reminder event is due. The pedometer element consists of a vertical row of LEDs that light up in the style of a battery charge condition display. It shows the daily activity progress by the number of illuminated LEDs. The more LEDs are illuminated, the more active the user was. The clasp controls the power supply. When it is opened, the bracelet is switched off. Integrated into the clasp is a port to charge the bracelet, e.g., via USB. An invisible mode button on the clasp allows to switch off all the bracelet's displays.

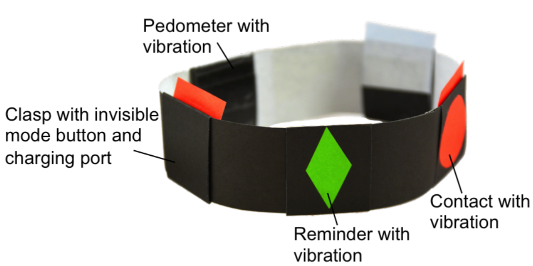

Figure 6. Design Concept C

Design Concept D

The female creator of design concept D (see Figure 7) emphasised that aesthetics is the most important design criteria. All elements have the same shape and are from one colour family. They are distinguished by patterns on their surface, such as triangles or lines. Each element has a discreet push button that is slightly risen and coloured like the element. To initiate a contact making, the user pushes the button on the associated contact element. If someone is making contact, small appliqués on the associated element light up and the bracelet vibrates. When an event is due, LEDs integrated into the reminder element light up, but not the whole element. All elements light up in the same colour, also elements from different applications. The pedometer element continously displays the number of steps. If a user pushes the LEDs on an element, the light will turn off. The bracelet should allow a maximum of six elements. As with designs A and B, the clasp of the bracelet includes a button to (de-)activate the invisible mode. The creator of design D preferred to configure the bracelet by a smartphone application rather than by a computer.

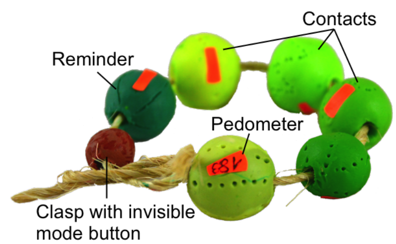

Figure 7. Design Concept D

Design Concept E

Design concept E (see Figure 8) was created from a member of the research team and discussed within the workshop. Elements are threaded on a silver string. A core element controls all other elements and is equipped with a button to (de-)activate the invisible mode. The button is hidden under small gemstones. Contact elements can have different shapes, e.g., a heart, whose border lights up when the user is being contacted. Additionally, the core element vibrates to indicate the contacting. Each element has a button on the side. The user can initiate a contact making by pushing the button on the associated element. Another element with a specific shape implements the reminder application. When a reminder event is due, a flashing light discreetly shines through the shape of the reminder element. The colour of the flashing light can be configured by the user, e.g., by a smartphone application.

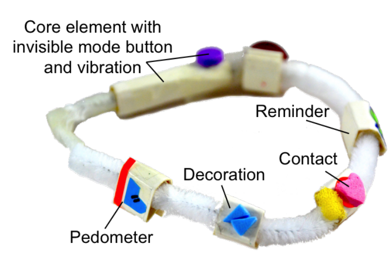

Figure 8. Design Concept E

The pedometer element is shaped like a shoe. A light on the left border lights up in red (little progress), yellow (middle progress) or green (big progress) to indicate the user's activity progress. Like with Design C, the bracelet's clasp controls the power supply. Decorative elements complete the bracelet. Workshop participants criticised that only the borders of elements light up, because that would be too unobtrusive. The idea of a core element that acts as a controller was welcomed, as well as the appearance of the design.

FINAL DESIGN CONCEPT

From the results of the requirements analysis and the prototyping workshop we derived the final concept of the modular digital bracelet (see Figure 9). The majority of designs implemented the idea of one string on which elements can be threaded (B-E). This concept is the basis of our design. Elements implement the applications non-verbal communication, reminder, and pedometer. They can have different shapes to be distinguishable and to be part of a collection. Their shape can indicate a certain application, certain contacts or reminder events (A-C,E). A core element included in a clasp controls all other elements. It includes the general hardware, such as microcontroller and battery, as well as a vibration motor and an invisible mode button (A-E). The clasp controls the power supply (C,E). Elements exist for each application resp. each contact person (A-C,E), but also decorative only elements can be used. Elements are threaded on a string with a railing system for that they are horizontally moveable on the string, but in a fixed vertical position. Thus, the user does not need to turn an element to see its display. Each element has LEDs included which indicate notifications and status information, such as an incoming contact making, a due reminder event, or the physical activity progress (A-E). Vibration signals are used to confirm an input and to notify of an incoming contact making (A,B,D,E). They are emitted from the core element only (A,E). Because the bracelet hangs loosely around the user's wrist, it can turn and elements change their position in relation to the wrist. This makes it nearly impossible for the user to map detected vibration signals on specific locations to specific elements. Therefore, the bracelet has one universal vibration motor. Each element consists of a push button that is hidden within the element and can be activated through a push on the LEDs or appliqués (A,B,D,E). The concept provides a smartphone application that allows to configure the bracelet via bluetooth, that is, e.g., the mapping of applications to elements, light colour of LEDs, vibration signals, reminder events, and offers further features with regard to the apps on the bracelet (A,D,E). In the following we describe the handling of the bracelet's applications. As our research focussed on the bracelet rather than the smartphone application, we do not detail the smartphone application.

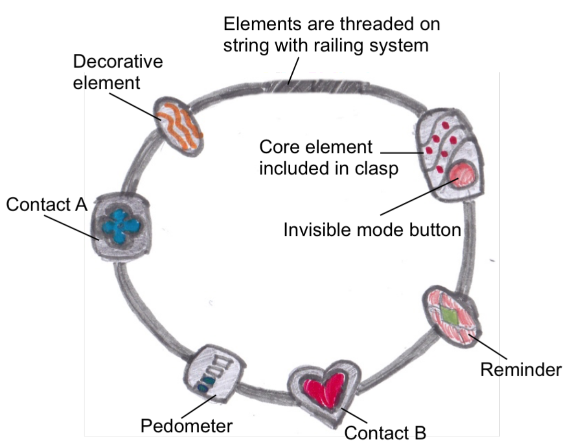

Figure 9. Final design concept of the modular smart digital bracelet. A core element controls all other elements, that implement the applications non-verbal communication, reminder, and pedometer in form of tangible apps. Information is displayed through light and vibration. Input is done through the push of a button on an element.

Non-verbal communication

The bracelet can contain several elements that represent specific contacts. The user can initiate a contact making by pushing the button on the associated element (A-E). The input is confirmed by a short vibration signal. On the bracelet of the person who was contacted, the associated element lights up (A-E) and three short vibration signals are emitted (A,B,D,E). The light remains illuminated until the contacted user pushes the button on the associated element. If the contacted user does not react within an hour, the light will switch off automatically. The contact making is processed by the associated smartphone application and communicated via mobile network. With the application, the user can also configure contact elements and light colours.

Reminder

The bracelet can contain several elements that represent single reminders. When a reminder event is due, the associated element flashes (C,E) in a *bright flash* pattern, i.e. the light turns on and its brightness very quickly increases and decreases three times, before it turns off and the next flash follows after half a second [9]. The element flashes for 20 seconds, because this was found to be the maximum reaction time to a light display on the wrist [10]. If the user wants to turn off the flashing within this period, she pushes the button on the element. If the user does not react, the element will flash again for 20 seconds after 5 minutes. If the user still does not react, the element will remain illuminated continuously for another hour. If the reminder is set up for a recurrent event that recurs within this period, the element will start the flashing procedure immediately when the next event is due. With the smartphone application the user can configure the reminders, and customise light colours.

Pedometer

The bracelet can contain an element that represents a pedometer. The measurement of steps is outsourced to an external pedometer, e.g., a clip or a smartphone application. The element displays the daily activity progress by four bars in tiers, which light up according to the progress. The more steps the user has taken, the more bars light up (C). This concept is based on a battery charge condition display. A bar represents 25% of the daily goal. To activate the display, the user pushes the lights, and the display will be illuminated for a few seconds (A,B). Daily goal, reset time and light colour can be configured by the smartphone application. Initially, the display will be reset at midnight and the light colour is blue, because blue has a calming effect and is not perceived as evaluative.

IMPLEMENTATION

In the following we describe the implementation of the final design concept in the form of a runnable, wearable prototype. To keep the implementation incomplex, we simplified the design concept and fixed the elements. Also, as a smartphone application for configuration was not necessary for the evaluation, we only focussed on the implementation of the bracelet.

The prototype (see Figure 10) consists of a reminder element, a non-verbal communication element, a pedometer element, and a core element. The elements are fixed on a string that was made of silver wire. The core element is mounted next to a magnetic clasp. We mounted a *LilyPad Arduino 328 Main Board*, an *Adafruit Micro LiPo w/MicroUSB charger*, and a *LiPo battery 3.7V 400mAh* to an additional armlet to keep the size of the bracelet minimal and thus keep it closer to the design concept. We connected the components on the armlet and on the bracelet with enamelled copper wires coated with a shrink tubing. To protect and hide the electronics on the armlet, and to increase wearing comfort, we whipped it with black felt. The silvery magnetic clasp controls the power supply. For the bracelet, we used the smallest electronic components we could find and handle. The core element consists of a *Shaftless Vibration Motor* (10x2.0mm), and a *Mini Pushbutton Switch - SMD* (6.4x5.5mm). The reminder and non-verbal communication element both consist of an *Adafruit NeoPixel WS2812 5050 RGB LED* (5x5mm), and a *Mini Pushbutton Switch - SMD* (6.4x5.5mm). The buttons are mounted beneath the LED on the non-verbal communication element, and on the left side of the reminder element. The pedometer element consists of four blue *1.900mcd WEABL02-C1S LEDs* (1.8mm), and a *Mini Pushbutton Switch - SMD* (6.4x5.5mm) mounted beneath. We slotted a dropping resistor in ahead the vibration motor, push buttons, and blue LEDs.

To form the elements we kneaded white modeling clay into different shapes, such as a heart (contact element), oval (reminder), and rectangle (pedometer), and formed it around the electronic components. We painted the elements with black and silver acrylic paint and garnished them with little decorative stones. We wrapped silver wire around the copper wires to form the bracelet and enhance a jewellery look.

Figure 10. Left: Prototype of the *Tangible Apps Bracelet*. Elements are made up of modeling material that diffuses the light of underneath mounted LEDs. LEDs are glued on push buttons. Elements are kneaded into shapes and garnished with acrylic paint and appliqués. Silver wire is wrapped around copper wires to form the bracelet and enhance a jewellery look. Right: User pushes an element to make an input.

Scenario

The prototype was programmed in the Arduino Programming Language. We implemented a scenario machine prototype, i.e. the prototype can only be used along a predefined scenario. The scenario covers all applications and important interactions:

After the bracelet is put on, it switches on and confirms this by vibrating for 200ms. Then, two LEDs of the pedometer light up blue. After a short time, i.e. 45s, a third LED on the pedometer lights up and simulates that the user has been physically active in the meantime. When the user pushes the button on the pedometer element, the LEDs turn off. Afterwards, an incoming contact making is initialised by three short vibration signals and a red LED on the non-verbal communication element. Through a push on the button of the element, the LED turns off. The user pushes the button again to recontact the person. A short vibration signal confirms the input. After that, the bracelet simulates that a reminder event is due. Therefore, the LED on the reminder element flashes green in a *bright flash* pattern for 20s. To simulate that the user has not recognised the flashing, it starts again after a short time and remains illuminated after the flashing. In the end, all LEDs that had been illuminated during the scenario light up. Because the user takes part in a notional meeting, she activates the invisible mode by pushing the button on the core element. A short vibration signal confirms the input and all LEDs switch off. After the “meeting”, she pushes the button again: the invisible mode is deactivated and all LEDs light up again.

EVALUATION METHOD

Using the scenario machine prototype, we conducted a lab study to investigate User Experience and Usability of the *Tangible Apps Bracelet*.

Material

For the study we used the *Tangible Apps Bracelet* prototype. To measure usability and user experience, we used two established standard questionnaires, i.e. the System Usability Scale (SUS) [3] and the AttrakDiff [11]. With the SUS, participants rate 10 statements, e.g., “I thought the system was easy to use.” on a 5-point Likert scale, ranging from “Strongly disagree” (1) to “Strongly agree” (5). With the AttrakDiff, hedonic and pragmatic dimensions of user experience are studied with 21 seven-point semantic differentials, e.g., “connective” (3) to “isolating” (-3).

Participants

20 volunteers took part in the study, which we conducted in *Oldenburg, Germany*. We chose only female participants with a general interest in jewellery, because the target group of modular bracelets is preponderantly female, hence, the design of the *Tangible Apps Bracelet* caters for females. They were recruited from personal contacts and included 11 university students, a pupil, 3 management assistants, a shop assistant, an

executive secretary, a dental assistant, a social pedagogue, and a media operator. Their age varied between 19 and 29 years (M 24.1, SD 3.2). We focussed on the age group 20 to 35 as this was defined as the primary target group for modular bracelets from the context of use analysis. Six participants owned a modular bracelet, e.g., a *Pandora* bracelet, and one of the participants a digital activity tracker wristband. Participants were not paid for taking part.

Procedure

Participants took part in individual sessions which lasted about 45 minutes. After they had signed an informed consent, we asked questions on previous experiences with modular and digital bracelets. We briefly explained the single applications of the *Tangible Apps Bracelet* and its overall concept, including the idea of an associated smartphone application. We also showed a sketch of the design concept (see Figure 9) to illustrate the appearance. Afterwards, we asked participants to name a contact person for the non-verbal communication element, so they could identify better with it. We helped participants to put on the armlet on their upper arm and the bracelet on their wrist. Then, the scenario started. We led participants through the scenario while we asked questions on the concept and implementation of the single applications according to a guided interview. We also asked questions on their understanding of the light encodings and vibration signals. For some questions, participants had to give ratings on 5-point Likert scales (1 to 5; the higher the more positive resp. agreement). After leading through the scenario, we conducted a post-test interview in which we asked for the overall experience with the *Tangible Apps Bracelet* and general feedback. Finally, participants completed SUS and AttrakDiff questionnaires.

RESULTS

In the following we report the results of the lab study. For the analysis, we coded the interview notes and evaluated the SUS and AttrakDiff responses. For the 5-point ratings, we calculated the mean value of a rating over all participants. Overall, the *Tangible Apps Bracelet* was perceived very positively, easy to interact with, and received very good usability and user experience ratings.

Applications

In the following we report the findings on the applications of the *Tangible Apps Bracelet*.

Pedometer

After we explained that the pedometer element shows the progress in relation to a preset daily activity goal, 18 participants were able to correctly name the displayed progress level, which was 75%, i.e. three illuminated LEDs. On a 5-point scale from 1 ("disagree") to 5 ("agree") participants scored the statement "The display is intuitive and I understand it." with 4.4 (SD 0.66). 3 participants would prefer the display – if dimmed and more decent – to be continuously illuminated, whereas the other 17 preferred to control the display, e.g., by deactivating it in certain situations. All participants would intuitively deactivate the display by a button. After they had searched for a button on the outer side of the element without success, they pushed the lights on the element. Participants liked this light-button concept very much. A participant noted she would like an additional vibration signal when another progress level is reached, for that she can perceive her activity status without focussing the display. Another participant said she experienced the blue LEDs that simulate a filling up as very motivating, and – in contrast to traffic light colours – as calm and relaxing. Overall, participants rated the implementation of the pedometer application as intuitive (M 4.5, SD 0.67).

Non-Verbal Communication

Participants found the vibration feedback that indicated an incoming contact making pleasant (M 4.8, SD 0.68). In combination with the illuminated light on the element, all participants mapped the vibration to a contact making and could correctly map it to the contact person they specified in the beginning. All participants intuitively pushed the button on the element once to switch off the light. To indicate a contact making, 7 participants intuitively pushed the button twice or thrice, whereas the other 13 participants pushed the button once again, which complied with the implemented concept. When asked, participants rated the implemented input method to initiate a contact making, i.e. pushing the button once again, as suitable and intuitive (M 4.8, SD 0.43). All participants perceived the vibration feedback after the user pushed the button to recontact the person as helpful and well-suited (M 5.0, SD 0.0). Further, some participants found it useful to enhance the concept by enabling urgency levels of a message, and different preset messages. A user could, e.g., push the button once, twice or thrice to indicate a certain message or urgency level. Overall, participants rated the implementation of the non-verbal communication application as intuitive (M 4.9, SD 0.3).

Reminder

Participants liked the *bright flash* pattern that indicated a reminder event and found it suitable (M 4.9, SD 0.48). A participant explicitly stated that she recognised the blinking, but did not feel disturbed by it and could easily continue talking to the experimenter. 19 participants experienced the duration of the blinking pattern as ideal, considering that it will recur after a short time if the user does not react in the first time. One participant experienced the duration as too short. 14 participants agreed that the blinking pattern is sufficient to gain the user's attention, whereas 6 participants did not agree. The main reason for their disagreement was that they feared they could miss the light, and therefore would like to receive an additional signal, e.g., in terms of vibration. Overall, 11 participants considered an additional vibration signal as helpful. 19 participants appreciated that the light on the reminder element remains continuously illuminated if the user does not react to the recurring feedback signal. In general, the feedback via the *bright flash* light pattern was thought to be good (M 4.5, SD 0.67) and the implementation of the reminder application was rated as intuitive (M 4.8, SD 0.43).

Invisible Mode

All participants found the invisible mode a useful feature. All participants intuitively pushed the button on the core element to switch on the Invisible Mode. Their rating confirmed that this concept was intuitive (M 5.0, SD 0.0). All participants considered the vibration feedback that the Invisible Mode is switched on necessary (M 5.0, SD 0.0). All participants wanted to be always in control about the deactivation of the Invisible Mode, in that they can manually deactivate it, e.g., by another push on the button. In addition to this, 5 participants liked the idea that the Invisible Mode is automatically deactivated after their working day in case they forget to do this.

Overall Experience

Overall, all participants liked the input concept and found it intuitive and easy. They rated the overall interaction with the *Tangible Apps Bracelet* as very good (M 4.9, SD 0.36), and liked that all inputs on the bracelet are made by pushing a button, and no other input techniques. A participant stated that buttons should be either located on top of the elements or face the user's hand as this would simplify the input. In general, participants liked the idea to configure the bracelet by a smartphone application, which allows to keep the interaction with the bracelet itself very simple. They agreed that the outputs satisfy their information needs (M 4.6, SD 0.58), except for little extensions as described above. Overall, the comprehensibility of all displays was rated as good (M 4.8, SD 0.54). Participants were aware of the vibration as a feedback for the activation of the bracelet, but did not feel disturbed by it. They rated the vibration feedback as very good (M 5.0, SD 0.22) and helpful (M 4.7, SD 0.57). All participants stated that a feedback signal is needed to know if the bracelet is working. In addition to light, all but one participant preferred vibration over other modalities, because it is very discreet and can be perceived without looking at the bracelet. Participants welcomed that the bracelet is switched off when put off, instead of set to a standby mode. They valued the bracelet as an individual, personal item with a high order of customisability. Participants rated the appearance of the *Tangible Apps Bracelet* as very good (M 4.8, S 0.54), on the assumption that the system is implemented as described in the design concept, i.e. with a railing system, and that it looks like a real piece of jewellery. The wearing comfort was rated as good and comfortable while walking (M 4.7, SD 0.48). 17 participants would like to use the *Tangible Apps Bracelet* if it was refined into a product. Reasons for abominations were a lack of technical interest, or that there was no need felt for the applications provided. Further, some participants mentioned that the bracelet should be waterproof and easy cleanable.

Usability

The SUS score for the *Tangible Apps Bracelet* was very high (M 94.75, SD 3.62). Hence, the Usability of the *Tangible Apps Bracelet* was rated as excellent.

Attractiveness, Hedonic and Pragmatic Quality

Overall, the scores of the AttrakDiff were high, i.e. the overall user experience of the *Tangible Apps Bracelet* was rated as very good. In all four dimensions, the *Tangible Apps Bracelet* was rated as optimal, with best ratings in attractiveness (ATT; M 2.48, SD 0.4) and hedonic quality - identity (HQ-I; M 2.31, SD 0.61), and slightly weaker ratings in pragmatic quality (PQ; M 2.1, SD 0.44) and hedonic quality - stimulation (HQ-S; M 2.01, SD 0.57). Figure 11 shows a diagram of the mean values. In detail, all single ratings were above-average, except for *technical-human*, i.e. the *Tangible Apps Bracelet* was rated as slightly more technical than human. Overall, the results show that the *Tangible Apps Bracelet* optimally assists users, they can identify with it and it stimulates and motivates them.

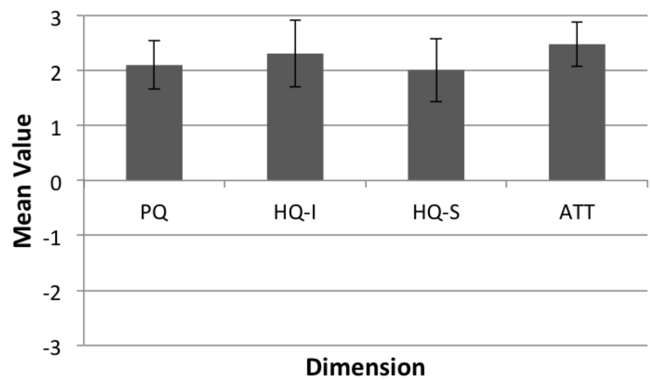

Figure 11. Diagram of mean values of the AttrakDiff. The *Tangible Apps Bracelet* received optimal ratings in all dimensions.

DISCUSSION

In summary, the results of the lab study show that the *Tangible Apps Bracelet* was perceived very positively, easy to interact with, and received very good usability and user experience ratings. We found that it optimally assists the users, that users identify with it and are motivated and stimulated by it. Also, participants found it very attractive. They appreciated the seamless integration of applications and digital components into a piece of jewellery and were highly willing to use the *Tangible Apps Bracelet* if it was refined into a product. Further, participants could easily comprehend and handle the several applications on the *Tangible Apps Bracelet*. We found small standard deviations for all ratings, i.e. the specific ratings during the interviews, the SUS, and the AttrakDiff. This indicates, that participants concurred in their assessment, and strengthens the results.

The study revealed, that the combination of light and vibration as output modalities is very usable and highly preferred. With the reminder element, we found that for a bracelet, light only is not sufficient to gain the user's attention. While light is generally suitable to present information in a decent and encrypted way on a piece of jewellery, vibration signals should be added to notify of urgent information, and are useful to confirm user input in cases where the input would not be observable otherwise.

The study showed that it does not make sense to search for an all-fitting design of the bracelet in terms of, e.g., its colours and the shapes of elements. As it is seen as a piece of jewellery, people want to make it individual. For *Smart Digital Jewellery*, this means it needs to offer a high order of customisability. This includes the appearance of the hard components, e.g., elements, as well as the colour of the lights integrated. In addition, there should be a couple of applications users can choose from. Also, the final design of the *Tangible Apps*

Bracelet is influenced by current jewellery trends in Europe. Thus, the results regarding the appearance of the bracelet, e.g., that elements are threaded on a string, are to be seen on a more conceptual level, as they might change over the next years.

Overall, participants appreciated the simple information display on and easy interaction with the bracelet itself. Particularly for a wearable, almost always observable display, the purposely limiting of information is pleasant and helps to counter information overflow. Further, low-resolution, i.e. point light displays can be discreetly integrated into a piece of jewellery without interfering with the jewellery's appearance. The study results suggest that directly on *Smart Digital Jewellery* information should only be presented in a limited way and only basic interaction should be offered. For applications that need a more detailed view and complex interaction, either they might not be suitable to run on *Smart Digital Jewellery* at all, or an associated smartphone application could be offered. However, designers should keep in mind, that *Smart Digital Jewellery* is classified as a wearable computer, and as such, it should not distract a user from her primary task and be accessible quickly and with little effort [15, 20]. The implementation of complex display and interaction concepts into *Smart Digital Jewellery* contradicts these requirements, as well as our study results, and therefore should be avoided.

Lessons Learned

In the following list, we summarise the lessons learned for the design of multi-purpose smart digital bracelets.

Aesthetics and Functionality

- Bracelet is seen as an individual, personal item that needs to offer a high order of customisability (appearance of bracelet and elements, choice of applications)
- Several applications should be offered; popular are non-verbal communication, reminder, and pedometer
- Three different applications could easily be handled on a single piece of *Smart Digital Jewellery*

General Use and Interaction

- Vibration and light in combination are well suited and liked to present information and give feedback
- Light generally suits to notify and to present information
- Vibration suits to confirm user input and to gain the user's attention for important information
- Information presentation should be limited
- Complexity of interaction should be kept low: Only a push button for all inputs was highly appreciated
- Push buttons should be placed in a way they are easily accessible for the spare hand
- Bracelet needs an invisible mode; user has to be in control about its (de-)activation
- Bracelet should switch off automatically when put off
- Feedback that digital piece of jewellery is switched on is mandatory

Reflection of Methodology

We found that for early prototypes, some AttrakDiff ratings are not meaningful. For example, participants rated the *Tangible Apps Bracelet* as more technical than human. Considering the prototype's stage of development, this was expectable and should not be rated negatively. This does not help or might even be misleading when assessing an early prototype.

CONCLUSION

In this work, we investigated how a smart digital multi-purpose bracelet should be designed in order to be attractive, functional, easily comprehensible, and easy to manage. On the basis of a participatory design process we designed and built a modular bracelet that integrates multiple applications in form of single elements that we call *Tangible Apps*. In a lab study with 20 participants, we evaluated the *Tangible Apps Bracelet* as a proof-of-concept implementation and assessed its user experience and usability. From the design process and study results we derived recommendations for designing multi-purpose Smart Digital Jewellery.

We identified an appropriate design concept for a modular multi-purpose bracelet. We found that it should consist of single elements that implement different applications and can be threaded on a string. Applications and appearance of the elements and the bracelet need to be customisable to form an individual piece of jewellery. Simple output and input techniques such as light combined with vibration, and push buttons turned out to be effective and appreciated. The results of a lab study showed that the *Tangible Apps Bracelet* was perceived very positively, easy to interact with, and received very good usability and user experience ratings. We found that it optimally assists the users, that users identify with it and are motivated and stimulated by it. Also, participants found it very attractive. They appreciated the seamless integration of applications and digital components into a piece of jewellery and were highly willing to use the *Tangible Apps Bracelet* if it was refined into a product. Further, our results show that users could easily comprehend and handle several applications on a single piece of jewellery.

Overall, from this research we conclude that multi-purpose *Smart Digital Jewellery* is desired, and implementable in form of an attractive, functional, and usable modular bracelet. From our study results we derived suggestions for the design of multi-purpose *Smart Digital Jewellery*. Hopefully, these will inspire and help designers of *Smart Digital Jewellery* and - if implemented - lead to highly accepted wearable devices.

A worthwhile next step would be to conduct a field study to see how the *Tangible Apps Bracelet* performs and is experienced in real-life environments. From the field study, we expect to learn about how environmental conditions influence the usage, usability and user experience of the digital bracelet. The insights would help to further improve the design of multi-purpose bracelets. To do this, we need to extend and refine the prototype. The joint work with a jewellery designer would help to enhance the appearance of the prototype. Furthermore, we are interested in investigating how to enable switching between different pieces of jewellery. Because people like to change their pieces of jewellery every now and then, we need to find how the applications of one piece can be transferred to other pieces, and how the interaction concept could be transferred to different jewellery forms, e.g., a ring.

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