Squeezy Bracelet - Designing a Wearable Communication Device for Tactile Interaction

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ABSTRACT
While smartphones are increasing in size and complex features, new form factors for simple communication devices are emerging. In this paper, we present the design process for a wrist worn communication device, which enables the user to send text messages over a paired mobile phone. The process includes concept design, user evaluation, design iteration, prototype implementation, and evaluation of alternative interaction techniques. Our particular focus is towards the use of naturally tactile interfaces in a wearable wristband form factor. We present how users perceive deformable communication device concepts and two alternative squeeze based interaction techniques.

Author Keywords
Wearable computing; mobile communication; concept design; prototyping; user experience.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Today, mobile communication devices have become a commodity, and people are used to the fact that communication technology is easily accessible and ubiquitous. However, the technical development of mobile communication devices has lead towards larger gadgets, employing high-resolution displays and touch screens as the primary input technology. Typical smartphones are currently equipped with screens starting from 4 inches, and often require two-handed use. At the same time, the complexity of the devices has grown, and due the number and variety of applications, navigation in the menus can require many steps, asking both attention and time. These factors result in mobile phone interaction demanding more time, precision, and cognitive load. Especially in the mobile context, where the interaction has been reported to happen in approximately four second bursts [15], complex devices are a challenge. Especially, handling a touch screen device while moving, e.g. walking, is prone to accidental interactions [14]. Taken together this provides motivation to investigate alternative interaction methods and form factors for communication technology.

Our research on the development of new means of communication builds on two emerging technology trends, wearable computing and deformable, tactile interfaces. We created concept designs of communication devices, and refined them based on feedback gained from a concept evaluation user study. Following this, a functional prototype demonstrating the selected concept's interaction technique was implemented in the form of Squeezy Bracelet, and evaluated with a user study (Figure 1). The bracelet functions together with a mobile phone, and is targeted for use cases, where the user needs to send a message quickly, easily, and in a subtle way to a predefined participant(s).

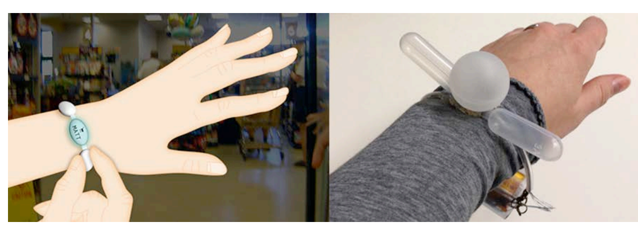

Figure 1. The Squeezy bracelet - interaction concept (left) and prototype implementation (right).

The contribution of our work is twofold. Firstly, we present user perceptions of different communication technology concepts, and secondly, we describe users' preferences on two types of squeeze interactions and design of a communication bracelet concept. Our findings have value for researchers and practitioners who work on developing wearable communication technologies.

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RELATED WORK

Emerging and Flexible Form Factors for Communication Technology

While off-the-self mobile communication devices are still bound to the conventional rectangular, mechanically rigid form factor of smart phones, research has started to propose different physical designs for the purpose. Examples include novel communication device concepts that have been investigated for children. Here, [17] has presented Pokapoo, which employs sharing of photos over networked toys, and [22] has investigated an interactive teddy bear concept for facilitating emotional communication between parent and child.

Recently, deformable devices and flexible materials have started to gain an increasing amount of attention. Schwesig et al. presented a flexible handheld device Gummi and investigated interaction concepts with it already in 2004 [20]. Interacting with deformable or foldable displays has been investigated from interaction point of view in several studies [9, 12, 18, 21]. In [11], stiffness and deformation range of a bendable handheld device was investigated, and soft materials were found to offer a more comfortable and engaging user experience. Flexible materials have also emerged in novel communication technology concepts, such as, MorePhone by Gomes et al. [6] and the Kinetic device mobile phone concept by Kildal et al. [10]. These research directions show the interest to develop physical designs that are more expressive, playful, and adaptive.

Wearable Computing and Wrist Worn Devices

Whereas conventional mobile communication technology has focused on handheld devices, wearable computing offers another approach for design. Holleis et al. [8] investigated user perceptions of wearable input controls when the user is in standing posture, and report that hands are one of the favoured body areas to place controls. Minimal interaction gestures are often favoured for their subtleness and social acceptability e.g. when interacting in public spaces [19], and this design principle matches well with interaction devices in the form of a bracelet or ring.

Bracelets and wrist-worn interaction devices have been utilized for interaction earlier in both industrial products as well as in research. Commercial wrist-worn devices include sports accessories such as Nike+ SportBand[1] for tracking jogging related measures such as pace, distance and calories, and Fitbit Flex[2] for activity and sleep monitoring. The Razer Nabu[3] has been introduced for combining the display of fitness data and personal textual communication content, such as emails. It uses two displays located on the opposite sides of the bracelet, the outer designed for public and inner for private content.

Probably the most common concepts for wrist-worn devices have so far been watch type computing devices, such as heart rate monitors or scuba diving watches. In research, the interaction with a watch type device is extended from the clock area to the wristband in the prototype developed by Perrault et al. [16]. Lyons et al. [13] introduced the Facet prototype, where small touch display units form a bracelet. Our research differs from these by taking an approach, which utilizes deformability as a design driver, and aims for displayless interaction.

Jewelry type bracelet concepts have been presented in [1] and [5], but, unlike us, without a prototype implementation and user study. As a smaller decorative wearable element than a bracelet, also interactive rings have been investigated as an input device. Ashbrook et al. [2] have introduced ring shaped interaction device Nenya, where the user interacts by turning the ring.

Positioning of Our Research

Earlier research on bracelets with communication functionality either rely heavily on graphical user interfaces (GUIs), where the display component is in a central role [13, 16], or early concepts, which have not yet been implemented or evaluated with user studies [1, 5]. In our research, we focus on a simplified interaction concept, which takes advantage of a form factor that is easily accessible, and allows communication with minimal cognitive load and even eyes free. Moreover, whereas aiming for an aesthetically pleasing concept, unlike to [1, 5] we bring our concept development to the level where the interaction is investigated with a functional prototype. In addition to the prototype and its evaluation, we present the design process, which highlights the roles of materiality and deformable interfaces as key design drivers in the concept development. We report novel finding on how these characteristics are perceived within communication device concepts, and present how those led to our final prototype.

ITERATIVE DESIGN PROCESS

In our research, we wanted to investigate device and interaction concepts for simple communication tasks in everyday life situations, where deformability and materiality were utilized as key factors in the design. By deformability we mean the possibility to e.g. compress, bend or twist. We conducted an iterative design process containing:

- brainstorming and sketching of the concepts
- co-designing with low-fi prototyping materials
- sketching of selected ideas
- concept evaluation user study
- development of a functional prototype, and
- its evaluation with users.

[1] http://nikeplus.nike.com/plus/products/sport_band/

[2] http://www.fitbit.com/uk

[3] http://www.engadget.com/2014/01/06/razer-nabu-smart-band/

The suitable hardware design and software development was done in parallel while refining the concept, and the findings from the concept evaluation user study were incorporated into the hardware and software design.

BRAINSTORMING INITIAL CONCEPT IDEAS

To start the concept design of deformable communication device concepts, the design process was initiated with a brainstorming session with a group of designers. This resulted in a list of key words and phrases, which served to set the overall scope for the design process - *wearable, flexible, transformable, transparent, utilizing sensors, enabling one handed interaction, social interaction, contextual awareness, novel, connecting things,* and *3D.*

Based on the key words, over a hundred sketches of ideas for wearable or handheld devices were created. The most promising of these sketches were then used as the motivation material in a co-design exercise with the target to further iterate the ideas. The session included 10 participants, who were researchers and designers with mixed backgrounds and worked in the project. Working in two groups, the participants used different arts and crafts materials to construct low-fi prototypes of wearable communicational devices, which could be new ideas or inspired by the presented concept sketches. This resulted 15 concept ideas in total, of which the participants then voted on the best concepts for further development (Figure 2).

Lipstick Pen (a) Origami Ring (b) Social Balls (c) Stretchable bracelets (d)

Figure 2. Four selected co-design session designs.

Based on the initial co-designed concepts, four more detailed concepts were developed to be evaluated with a user study. The *Flexi Stick* concept (A, Figure 3) was an iterated version of the "Lipstick Pen" (see Figure 2, a), which could be extended and bent to launch applications and bend itself as a form of feedback. This also included a virtual marker feature for drawing and scanning virtual graffiti markers. The *Knots & Balls* concept (B, Figure 4) was an iterated version of the "Stretchable bracelets" and "Social balls" (Figure 2, c & d). We decided use two versions of the concept in the user evaluation, a ball and a bracelet. Both versions used tangible interactions of squeezing and pulling, but the ball version had a screen whilst bracelet did not. The *Origami Brooch* (C, Figure 5) was a simplified and more gender-neutral version of the "Origami ring" (Figure 2, b) which used tangible interaction to create messages by opening the origami in different ways. In the brooch format, it can be worn anywhere on the user's body. As an extension, private, semi-private and public areas were included in the brooch. The *Blades* (D, Figure 6) concept was inspired by the "Stretchable bracelets" (Figure 2, d) and other wrist-worn device ideas. With an incoming a message, the bracelet gets warm and the blade corresponding to the sender begins to bend and shows the message written on the blade.

FIRST CONCEPT EVALUATION STUDY - USER STUDY I

Concept and Use Case Development

As a next step, the selected concepts were further developed by sketching the use cases and features in more detail. To guide the scope of concepting towards deformable form factors, the following principles were prioritized:

- easy accessibility for use e.g. wearability
- fast interaction
- simple communication
- expandability - more information or features obtained through modularity or deformability
- privacy preserving, or separating private/public UI
- materiality used for engaging user experience
- aesthetically pleasurable.

The dominant theme of the use cases presented in the co-design phase was that of sending messages to family or close friends. Hence, we decided to present each concept in an everyday messaging context where holding a mobile phone in the hand is problematic, for example, when shopping and holding bags in both hands. Therefore, we created a use case story where a user is in the city shopping and receives a message from a close friend. The developed concepts A-D and example use cases are presented in detail in the Figures 3-6. The use scenarios are described in the form they were explained to the user study participants.

Set-up for Concept Evaluation User Study

The concepts A-D were evaluated in a user study with the objective of investigating perceptions with the designs, as well as for finding the best concept for further development.

Participants

Altogether, 16 participants were recruited to the user test in pairs. All the subjects knew their partner, and they were encouraged to talk aloud to each other whilst evaluating the concepts. Participants' ages varied from 27 to 49 with a mean of 35 and 68% were female. All the subjects had a touch screen mobile phone, and 50% of them had experience with wearable computing e.g. heart rate monitor.

Procedure

The study was conducted in a laboratory setting and video recordings with observation notes were taken. The focus of the study was described to the participants as aiming to find alternative methods than mobile phones to interact with close friends and family members, when in everyday situations. The subjects were shown each of the concepts on a large screen TV. The moderator described each concept and presented step-by-step use cases (Figures 3-6, steps 1-4/5). Subjects gave their comments and ideas on each concept, and then completed an Attrakdiff [3] inspired 7-point (-3,-2,-1, 0, 1, 2, 3) antonym word pair questionnaire.

A) Flexi-Stick
The user is walking in the city when the device vibrates in her pocket (1). She takes it out and expands it by pressing both ends of the device with her thumb and index finger (Figure 3, 2). She reads the message from her friend: “Meet me in the new shop”. She then taps a linked location and navigator application opens and she bends the device to expand it to full screen (3). The device then directs her to the shop by physically bending its end to point in the correct direction (4). When a user arrives at the location, she uses the device to scan the shops’ doors to find a virtual message that her friend might have left (5). She finds a cross on one door and the text: “I am here”.

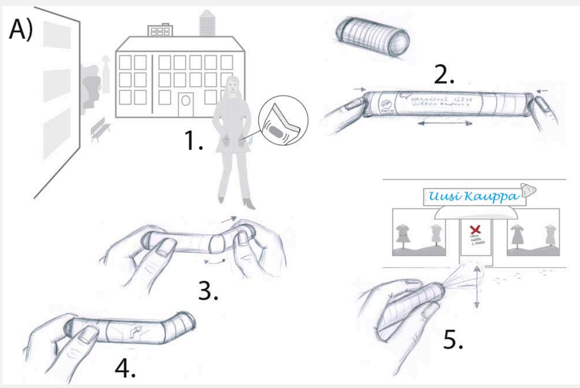

Figure 3. Flexi-Stick concept and use case.

B) Knots & Balls
The user is walking in the city and feels and hears a tingling sensation in her pocket (1). She takes the ball shaped device out of her pocket and notices that the sub ball which indicates her friend is red and in the center ball there is a message: “See you in the Café in 30minutes?” (2). She wants to go and answers “OK” by pulling her friends ball away from the center ball and releasing it (3). Within 30 minutes she goes to the Café (4). The alternative of a wrist-worn version of the device was also presented with alternative squeezable interaction (5).

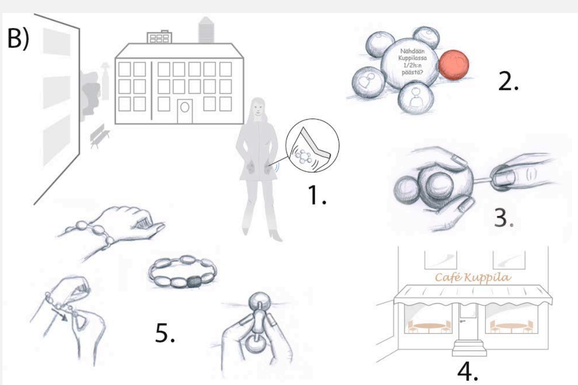

Figure 4. Knots & Balls concept and use case.

C) Origami Brooch
The user is walking in the city has a brooch on the sleeve of her jacket (1). When the Origami is open, it collects messages while the user walks in the city. When a message arrives the Origami closes. Received messages can be checked by taking the brooch in hand (2). The Origami has three types of information: public, semi-private and private, located in different facets of it. Public information such as advertisements can be seen or shared from outer facets, but the private messages from her friend are located deeper inside of the Origami (4). The user wants to see private messages, so she turns the Origami around and presses it, causing it to open as a flat surface and show the private messages (3). When the user wants to send a short answer message, she does it by folding the Origami (5).

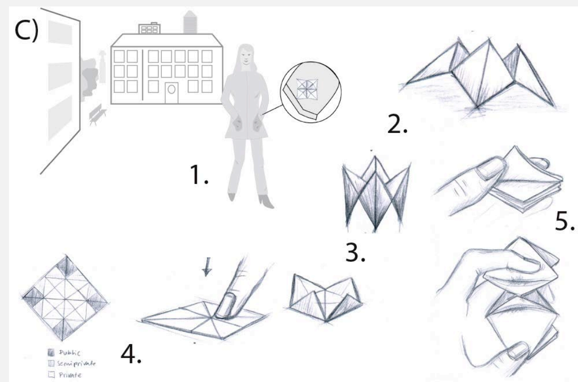

Figure 5. Origami Brooch concept and use case.

D) Blades
The user has a bracelet on her wrist (1). The user feels warmth in her wrist and notices that her friend’s blade has curled, and on the blade there is message: “I am 15 minutes late” (2). The user sends “OK” message by pulling her friends blade (3). The user can also create customized messages by curling or turning blades to different orientations (4).

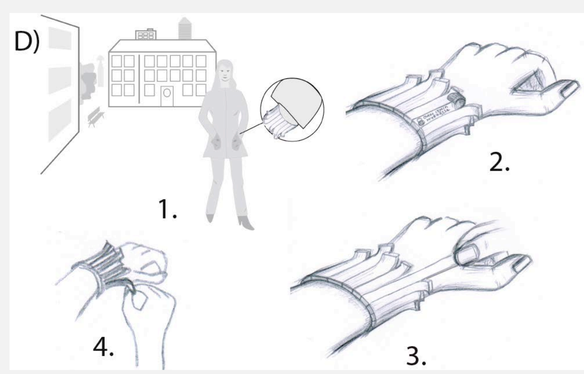

Figure 6. Blades concept and use case.

Results

The results of the antonym word pair questionnaire are presented in Figure 7. To establish the general significance of the results a Wilcoxon signed rank test was conducted between the *Knots & Balls* (the clearly preferred design) and the *Origami* concepts (the least preferred design). Due to the large number of combinations, it is not feasible to report the significance of measured differences between all pairs of designs.

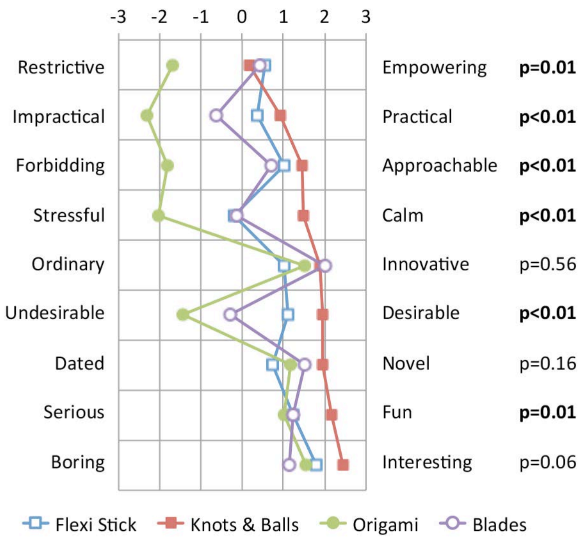

Figure 7. Antonym word pair evaluation of the concept designs. p-values are for Wilcoxon signed rank test between Knots & Balls & Origami concepts. Bolded p-values indicate a significant difference.

The *Origami* concept was the least favourite, and it was rated as very impractical and stressful. The visual appearance was perceived *"nice"*, but its perceived usability was commented as *"difficult"*, *"complicated"* and *"demanding"* as it was seen to require learning and recalling, making it rather error prone. As one stated: *"Help, how does this work?"* (Female, ID1). Subjects also stated that it could not be operated while moving and it required two hands, which was perceived negatively.

The *Blades* concept was rated to be highly innovative, but it was perceived to be problematic with clothes. As the curled blades may easily snag on clothes, causing unintended functions to be activated. Also one subject commented: *"Everything touchable is nice, but I would tinker it all the time"* (Female, ID9). The individual curling was perceived as *"creepy"* and *"stressful"*. The bracelet was also considered to be too wide and the space for message as too small. As one pair suggested: *"A larger area could be in use if you are communicating with one person in time, for example the whole wristband area"* (Females ID15&16).

The *Flexi Stick* concept was perceived from a device perspective as *"new"*. In particular the way the end of the device became a direction guide was perceived as *"handy"* and *"cool"*. Additionally, the tangible interaction for extending of the screen was perceived as *"interesting"*. However, the need for two-handed interaction was not liked, and it was as perceived as similar to a limited functionality mobile phone, as subjects commented: *"another device again"* (Female, ID2), and *"I wish more creative solution… it should be part of me"* (Female, ID8).

The *Knots & Balls* concept, and especially the bracelet version was perceived as *"emotionally appealing"* and *"simple"*. It was also perceived as *"useful"*, *"handy"*, and *"unnoticeable"*, as it could be worn on the wrist, and would be less easily lost than the ball version of the concept. One participant stated her wish for the design: *"It should fit to my style, clothes and other jewellery that I wear"* (Female, ID11). Another commented: *"I am not sure of its usefulness, if it is too big"* (Female, ID3). The "pulling one knot and releasing it" interaction was felt to be *"interesting"* and especially an *"easy"* and *"fast"* way to send short responses using one hand, as one subject stated: *"Really handy when you have grocery bags in your hands and you can easily answer with simple gesture*" (Female, ID2). For some it was somewhat unintuitive, as one stated: *"Why it has to be pulled?"* (Male, ID6) and another: *"Pulling is stressful"* (Female, ID7).

The *Knots & Balls* concept was clearly the preferred design (Figure 7), being significantly better than the *Origami* concept (the worst design) in all parameters except Innovativeness, Novelty and Interest. Thus the *Knots & Balls* was selected as the basis for the next design phase.

General Design Principles & Summary of Findings

As a summary of the findings, several general design principles for wearable devices could be extracted, as they became apparent from the concept evaluation user study.

1. The device should not move or physically transform under its own control.
2. The device should be designed in a way that works with the user's clothing, e.g. not to snag on them.
3. If the device has a physical appearance that invites the wearer to tinker it, its design should make it possible. In particular to allow use as a "stress ball" there should be the possibility to switch off the device functionality to avoid unintentional input events.
4. The device should enable communication with simple and fast interaction one-handedly.
5. The design of the device should be as small as possible and fit with user's clothing and jewelry fashion.

DESIGN ITERATION AND PROTOTYPE BUILDING

Further design iteration of the selected bracelet version of the *Knots & Balls* concept was made. The focus of this design phase was on the user interaction. As in the concept evaluation use case there was only sending a reply with "pull" interaction presented. We needed to explore ways to also to create messages. Although already in the concepting phase we considered creating messages by tying knots in string, as Incan Quipu writing, this had been discarded as it was felt prone to error. Additionally, considering design principle number 4, it was not suitable solution for one-handed interaction. Thus, we started to explore alternatives.

In particular, a more flexible method of creating messages was searched. We decided to try squeezing because it was flexible enough, but also quite unnoticeable way to interact. For the same reason we changed the concepts "pull to send" interaction to a squeezing interaction for sending messages. This also enabled the possible support for a larger amount of contacts, as it removes the requirement to have separate balls for each contact. Therefore, the bracelet was designed with three balls, such that the central ball provided the output channel whilst the others were used for input.

The five design principles were incorporated to the final design (Figure 8, 2-3) as follows. 1. There are no individually moving parts in the bracelet design as the squeezing is user generated. 2. The design of the bracelet is as petite, thin, and snag free as possible. The balls in the bracelet are squeezed from one side so it would not snag clothes and be as unnoticeable as possible under the clothes. 3. The bracelet has three balls: one for message creation, another for seeing the content of the message and the last for sending it, so the user is allowed to tinker with one ball (message creation) without fear of unintended sending. 4. The squeeze interaction was selected, because we found it to be an easy and fast way to both browse and send messages one handedly, but also it is more "snag free" than the "pull" interaction presented in the user evaluation of the concepts. 5. The body of the bracelet is translucent and it is possible to define the color of the middle ball and use it as a decorative element when no user interaction is made, to make it fit with different colored clothes.

Then we started to test suitable squeezing interactions for the bracelet with the idea to prepare a prototype that could be used to study how users perceive the interaction and the three-balled bracelet. Therefore, in the constraints of the technology available and the time, we decided to test interaction with simple accessory prototype to be used with a mobile phone, rather than a stand-alone device. With this prototype the messages are pre-written on the mobile phone, and in situations where the use of mobile phone is difficult, the bracelet is used to select and send the message.

Use Case Definition

The use case we defined for the evaluation followed a fictitious user, Paula (Figure 8, 1-4). She and her husband had planned in the morning that she will buy groceries and her husband will collect her from the shop. Hence, now prior leaving from the office, she pre-writes a message on her phone "At the checkout desk!" (1), and assigns it to a turquoise color that she can remember. When she arrives at the checkout, she uses the bracelet device on her wrist to browse the messages that she has created with the phone (2). She finds the turquoise message (with inner ball) that she created at her office. Then she selects the receiver, Matt, her husband (with outer ball) and sends it to him (3). Matt is arriving to the parking lot, when Paula's message arrives to his phone, he knows that it will only take a few minutes for Paula to come out of the shop, so rather than parking, he drives to waits at the front of the store (4).

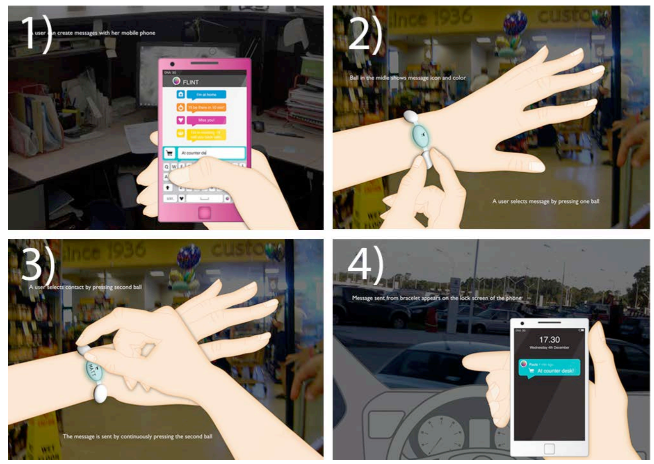

Figure 8. Bracelet design and use case (1-4).

Bracelet Prototype

The target of our implementation was to create an interaction that included physical deformation, as it naturally provides haptic feedback, making it ideal for our semi-blind use case. We experimented with different approaches and materials for the construction and finally settled on using small plastic Pasteur pipets obtained from the pharmacy as the physical interface. Interaction would be by the user squeezing the pipet. An air pressure sensor placed inside the pipet would provide data on the deformation state of the sealed pipet, and drive the message selection mechanism. The prototype HW was constructed using an Arduino compatible microcontroller (www.iprotoxi.com). In addition to the controller board, the HW included two barometer air pressure sensors, three RGB LEDs, a Bluetooth board for connectivity and a small battery (Figure 9). The air pressure sensors were placed inside the pipets, which were then sealed forming the squeezable interface. The LEDs were attached to a translucent plastic ball to provide pleasant light dispersion.

Software Design

The software in the bracelet Arduino read the values of the 2 pressure sensors every 10ms and reported the values via Bluetooth to the attached Android smartphone. The main application logic resided in the Android smartphone, Squeezy application. When the application was launched and connected via Bluetooth to the bracelet, pressure measurements from the bracelet sensors were received.

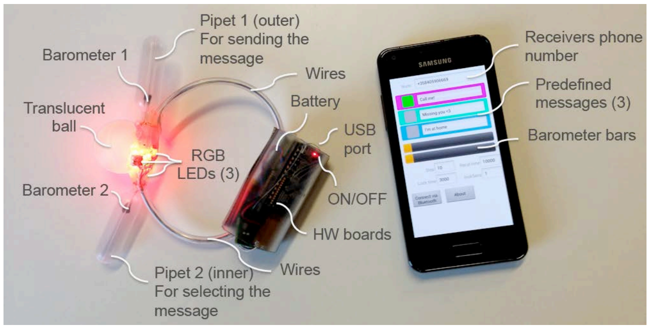

Figure 9. Functional prototype - bracelet and mobile phone UI. Pink message selected in the application.

The application first performed a calibration step, to set the initial "zero" pressure level corresponding to the non-squeezed state of the pipets. Because the pipets were not perfectly elastic and did not always return to exactly the same internal pressure when released the calibration function was repeated automatically when the application identified that there had been no major changes in the pressure level for 10 seconds. Thus potential drift in the interface was largely avoided.

The Squeezy application's functionality was rather simplified. As we were interested in user's perceptions of the new version of the bracelet and the squeezing interaction, the application functionality needed only to present a representative context for the interaction. Hence, the application allowed the user to define one phone number to which text messages would be sent, and to define three different text messages to be sent, based on the bracelet interaction. All the messages were color coded in the UI to match with the color that was used to represent the selection of that message in the bracelet UI (i.e. via the RGB LEDs).

Alternative interaction mechanisms

To study the squeeze interaction, we created two variants of the application that utilized different ways to interact with the bracelet. In both variants squeezing the outer pipet above a defined threshold level, caused a text message to be sent from the attached smartphone. The method to select the particular message to be sent differed between the two variants. In each case the selected message was indicated to the user via the color of the LED on the bracelet.

Pressure Level Based Selection

In the first variant, the pressure level within the inner pipet, i.e. how hard the user squeezed the pipet, determined the sent message ("Analog interaction"). Thus interaction required the user to distinguish between three different levels of squeezing the pipet, corresponding to the selection of one of the three messages.

To enable one-handed use when the user maintained the pressure level at one of the three levels for more than a second, the selection latched to that level and the user was able to release the selection pipet. Latching was indicated by an increase in the brightness of the bracelet LED. The user was then able to squeeze the outer pipet to initiate sending the selected message. If the user did not activate message sending within three seconds the latching was released. The pressure levels and time windows required for the interaction were determined during a pilot test.

Toggle Based Selection

The second interaction variant looped through the messages with each squeeze of the inner pipet above a defined threshold level ("digital interaction"). For example, to move from selecting the first message to select the third message required the user to squeeze the inner pipet twice. In addition, by holding the pipet squeezed, the selection would loop between messages based on a timeout of 800ms.

PROTOTYPE EVALUATION – USER STUDY II

The prototype was evaluated in a user study, with the main objective of exploring users' perception of the solution and the two different squeezing interactions with the bracelet. Secondary objectives were to identify potential usage scenarios and to obtain feedback on the form factor of the bracelet device presented as concept images in the use case.

Participants

Of the 15 participants (60% male), 47% had also participated in the first user study. The participants' ages varied from 26 to 62 with a mean age of 39, and 14/15 were right handed. Altogether 14/15 owned a touch screen phone. All of them had some experience with wearable computing/ electronics, such as heart rate monitors (73%).

Procedure

The study was conducted in a laboratory setting, where observational notes were taken and it was video recorded. Seated subjects completed tasks and were interviewed semi-structurally during the tasks. Background information was first collected and an introduction to the study area was given. The use case story was described to the participants (Figure 8, 1-4) as an orientation to the study. The prototype device was fitted onto the user's wrist (Figure 1 on right), and the user was introduced to the mobile phone application UI, which contained three pre-written messages (Figure 9).

The test tasks were completed with both interaction variants, the order being counter-balanced between the users. Users were encouraged to comment aloud and following test to rate various aspects of the experience on a 7-point Likert scale (see Figure 10 for the rated aspects). In the test, users were asked to use the bracelet to select one message and send it. At first, the users were not instructed how to interact with the bracelet. Then if they did not discover how to interact with it, the moderator provided guidance. At the end, users selected their preferred interaction method for message selection (pressure level, single squeeze steps, squeeze and hold) and listed three useful usage contexts for the bracelet.

Results of the Prototype Evaluation

In general, participants liked the bracelet concept. As one participant stated: *"Funny, innovative idea, which could help messaging in everyday situations, when I do not want to take effort to find my phone or write a message"* (Female, ID4). Several different kinds of scenarios and example messages were proposed. For example, one suggested that it would be handy if the bracelet was linked to the phone calendar and she could use the bracelet for sending reminders to her husband, such as *"take the dog out"* and *"remember to go to the hair cut"* (Female, ID3).

Usage context

Our example shopping use case was not perceived as the best use context for the bracelet. Generally it was perceived to suit contexts where the user is not able to concentrate to the interaction and cannot use both hands, e.g. driving a car, cycling or running. As one participant stated: *"It would be really handy in situations where my hands are full with something else, for example…running with my dog when one hand is holding the dog's leash"* (Female, ID3). Another popular usage context was in a meeting, where users do not want to be interrupted or upset other members by using their phone to send a message. Also different use contexts were proposed. One user considered this kind of device as useful in situations where is needed to ask for help, i.e. as security bracelet (Female, ID8). Another one proposed it for military use (Male, ID6).

Physical Design

The physical design of the prototype received some criticism and suggestions. Particularly, the roles of the central light dispersion ball and the identical looking inner and outer pipets were not clear to all users. As one user commented, e.g.: *"It was disturbing that I had to use this other pipet for sending the message. Could I send the message by pressing this same pipet?"* (Male, ID1). Also another stated: *"It annoys me that sending is done from the other side with a similar looking pipet… the ball in the middle could be good for sending"* (Male, ID12). Also interaction with the outer pipet was not perceived to be as unnoticeable as with the inner pipet. According to the subjects, the bracelet design should be petite, stylish and elegant looking, and look like jewelry that would suit both business and leisurewear. It was also wished to be customizable and personalizable through additional parts, as one user stated: *"In the evening I want to put jewels in it"* (Female, ID10).

Interaction Mechanisms

Toggle based interaction

The toggle based application was generally perceived easy to use and control. Participants who started with this automatically interacted correctly (message selection) describing it as: "*easy", "great", "awesome" (Female, ID2*). Those who started with the pressure based variant stated that this was easier and more intuitive, as one user said: *"Now it worked as I thought the earlier* (pressure based) *would work… it was a lot nicer experience with this…I at once understood how it works."* (Male, ID15).

Pressure Level Based Interaction

The pressure-based interaction was generally perceived as difficult, non-logical and demanding. As one participant who used this application after successfully using the toggle variant commented: *"It does not ring the bell… I just don't understand the logic of this at all" (Female, ID2)*. Participants perceived adjusting the squeezing pressure as imprecise and difficult to control. Therefore it was perceived to be difficult to learn, one participant commenting: *"How can people learn the press levels." (Male, ID14)*. It was also perceived to be too demanding and needing constant attention, *"Impossible to interact with while moving…requires me to stop" (Female, ID8)*. Also the usage context was perceived to cause extra difficulties for the interaction, for example, *"When you are in hurry, it is difficult to keep the force of the press constant* (Male, ID11) and, *"It requires motoric skills and it is not possible to use it with eyes closed" (Male, ID6)*. Two users found it innovative, but they preferred the toggle interaction from a usability point of view. One stating: *"Analog selection is innovative, but not as good as the first one (Male ID13).*

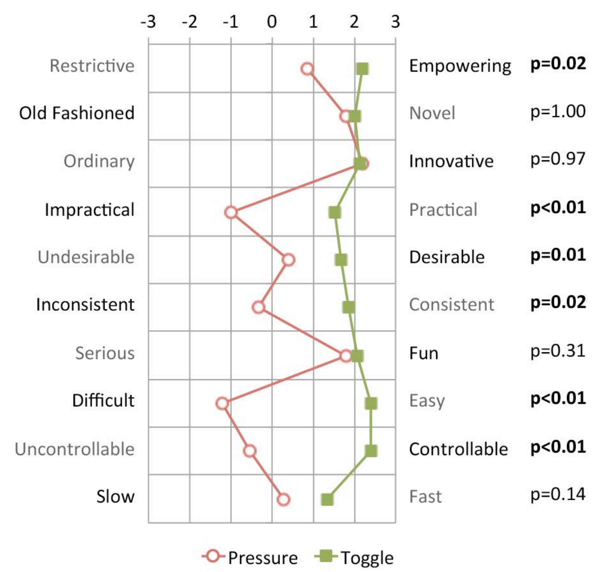

Figure 10. Subjective feedback on pressure and toggle interaction variants. Note: Survey questions were based only on the darker labels. For clearer presentation data from negative terms has been inverted. Parameters with bolded p values indicate significant differences.

Comparing Toggle and Pressure Based Interaction

The toggle based interaction was perceived to be easier than the pressure based variant to control. Users' subjective view of the two interaction variants is presented in Figure 10. A Wilcoxon signed rank test was conducted and indicated that users perceived the toggle interaction to be significantly better in all evaluation categories with the exceptions of Novel, Innovative, Fun and Fast. The lack of significance for Fast suggests that at least some users recognized the potential of the pressure level based interaction.

Altogether 86% of the users preferred the single squeeze steps interaction to select messages. Users commented that it was *"easy to control"*, *"clear"*, *"reliable"*, *"fast"*, and *"logical"*. Only one chose the continuous press, explaining: *"With frozen hands it is easier to press continuously!"* (Male, ID7). One user who selected single squeeze commented: *"In everyday use continuous might be better, but this felt more natural."* (Female, ID2). One explained pressure levels based selection: *"If it would work as intended, it would be the most fun and innovative alternative, but in basic use the single squeeze would be the reliable one."* (Male, ID14).

DISCUSSION

In our iterative design process we investigated the user perceptions of different kinds concepts of wearable communication devices. Test participants identified the need for a simple and unnoticeable communication device which they could interact one handedly with a tactile interaction method. Our findings indicate this kind of bracelet would be of benefit where eyes free interaction is needed, e.g. while driving, cycling, meeting, or running. Especially, it was emphasized that whilst on the go, repeatable communication needs often arise, e.g. the need to inform about being in time or late, or notifying of arriving or leaving at a location.

The concept evaluation showed that the design of the device should fit with users clothing and jewelry fashion both visually and functionally, e.g. it should not snag on them. Also the device, should not be designed as too physically aggressive, e.g. the device should not move or physically transform under its own control. The possibility to be able to tinker the device, without of fear of unintentional input events should be offered for the user.

Interaction

Our finding on the interaction techniques show that pressure level based (i.e. analog) interaction is not easy and intuitive for the users. It was perceived as too demanding and requiring too much attention. Prior art has also investigated pressure level based input with mobile communication devices [4, 7, 23]. Here, [4, 7] address sending vibrotactile messages between two mobile phones, whereas we consider a different form factor.

Wilson et al. [23], reports users being able to distinguish between 10 pressure levels with a similar thumb-index finger pinching interaction. However, in that case there was no deformation of the interface but rather artificially created feedback mechanisms used. Wilson et al. [23] highlights the continuous feedback of the level of pressure being applied as being a critical element. In our prototype, we hoped that this would be provided by the natural deformation and elasticity of the squeezable pipets. Supplementing the deformation with other feedback, e.g. vibra, may improve the usability of the interaction. Other sources of difference may relate to our wearable bracelet form factor vs. the statically mounted form used by Wilson et al. [23].

Semantics, Materials and Personalization Matter

The design of our prototype did not communicate well the affordance of the possible interaction and also from a semantic viewpoint was not clear. As examples, the light diffusion ball was perceived as an interactive element and the two pipets were identical looking, yet had clearly different functions. One challenge for the interaction mechanism was the range of different squeezing pressures that were used by different users, i.e. some squeezed softly, whilst some squeezed very hard. With better consideration of the perceived affordance this range of interaction could be reduced, perhaps leading to a more robust interaction.

The device was considered as jewelry by many users, who thus wished that the wrist device should be petite, unnoticeable, simple and suitable for both business and free-time wear. Further, personalization and customization are considered important for such a device.

Limitations Of Our Study

We acknowledge that our work is limited by the study setting. Whereas we implemented an interactive, functional prototype, the form factor was still that of an early prototype. However, as the main goal of it was to study how users perceive these two types of squeezing interactions, the prototype implemented was useful and provided rich user feedback. We also believe that the visualizations shown while describing the concept and use case enabled the participants to imagine a finalized design of the concept. Moreover, our study was conducted in laboratory settings, and testing in a real life use context may provide more data e.g. on usability and social acceptability of the concept. It would also enable comparison of interaction speed with the bracelet and the mobile phone while on the go with cognitive load. These are interesting topics for future studies.

There were also technical limitations due to the off-the-shelf prototype nature of our hardware, particularly the pipets, which were the key element in the success of the interaction. The use of purpose designed elements to replace the pipets, where the elasticity, size and shape may be specified may have a major impact on the interaction. Even though the physical deformability of our interaction was small in scale, it still provided users with a pleasurable feeling of natural resistance and physical change when interacted with. This study provides a good starting point for the future realization of a fully featured prototype with larger scale deformable interaction. One possible technology for future realization of this concept could be the PneUI [24] developed by Yao et al.

CONCLUSION

In this paper we looked at the conceptual design, prototyping and evaluation of a communication device concept, where wearability and deformability were taken as the key design drivers. We have presented an iterative design process, where the concept evaluation findings contribute to the knowledge of how people perceive the different elements of deformable communication device concepts. Here, especially the simplicity of interaction, holistically designed aesthetics, and personalization were highly preferred features, whereas e.g. actuated wearable devices were perceived as potentially suspicious or even creepy. Evaluation of our prototype Squeezy bracelet, for sending predefined messages, showed that the benefit of the concept was perceived to be in fast interaction requiring little cognitive load or visual attention, and that a toggle type selection methods by squeezing was preferred.

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