Reversed Voodoo Dolls: An exploration of physical visualizations of biological data

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ABSTRACT
Physical visualizations are artifacts that materialize abstract data. They take advantage of human natural abilities to interact with information in the physical world. These visualizations present an opportunity to be applied on new application domains. With the objective of discovering if physical visualizations can support remote monitoring of biological data, a technology probe is presented in the form of a reversed voodoo doll. This probe uses the natural affordance of an anthropomorphic figure to represent a person and reverses the concept of voodoo dolls in a playful way. The scenario of safety is selected for testing physical visualizations of bio-data. Two measurements from the human body, heart rate and motion are chosen as a light way to monitor remotely over a person’s conditions. During the study, a group of six participants were exposed to the technology probe and their interactions with it were observed. The study reports on the users’ interpretations of the data and uses given to the alternative modalities of the probe.

The results suggest that the data mapping to the object’s body parts was effective for conveying meaning. Additionally, the results confirm that the use of multiple modalities in physical visualizations offers an opportunity to present information in situated contexts in the real world. The degree of physicality achieved by the reversed voodoo doll and the effects of the selected metaphors are discussed.

In conclusion, it is argued that the responses and interpretations from the users indicate that the reversed voodoo doll served as a means in its own right to transmit information for monitoring of bio-data.

AUTHOR KEYWORDS
Physical data visualization; technology probes; ambient displays; data sculptures; biological data.

INTRODUCTION
Since Hiroshi Ishii proposed his vision of tangible user interfaces (TUI) [6] and its potential uses on information visualization were recognized, novel interaction techniques for information display have been proposed and studied over the years. From ambient displays to data sculptures, these visualizations exploit the natural abilities of humans to process physical information. Additionally, they have proved their potential as a mean of communication.

In parallel, continuous advances in portability and miniaturization of sensors capable of measuring human body conditions have made it possible to integrate these sensors into wearables. These devices produce real time data that has the potential to provide information about the wearer’s conditions. These systems generate a myriad of data that has been used across different application domains, for instance health [11, 20] and safety monitoring [2, 3]. Additionally, the need for novel ways for presenting information based on sensor bio-data has been pointed out [16], and the key role of information visualization in safety monitoring has been recognized [2].

Safety is defined as “the condition of being protected from or unlikely to cause danger, risk, or injury” [18]. The scenario of remotely monitoring a person’s conditions in order to know about this person’s safety presents an opportunity. In this scenario, there is a demand for visualizing information based on sensor bio-data. This information could be presented physically or graphically. In this work, physical visualizations are selected with the intention of studying the change from graphical to physical visualizations and test their potential on bio-data monitoring.

The objectives of this work are to discover if the direction of physical visualizations supports monitoring sensor bio-data, additionally to inspire designers to explore the design space of physical visualizations by identifying a new application domain. To achieve these objectives a technology probe [5] is proposed in the form of a “Reversed Voodoo Doll”. The probe uses the natural affordance that an anthropomorphic object has to represent a person. It reverses the concept of voodoo dolls from having effects on a person to knowing about this person’s conditions in a playful way. A group of six participants is exposed to the technology probe and presented with bio-data embodied on a physical object. The interactions with the reversed voodoo doll and usage given by the participants are observed and analyzed.

This document starts with an overview of research in physical visualizations. Subsequently shows the current state of the art of visualizations of bio data including both physical and graphical visualizations. Afterwards the study is motivated introducing the technology probe. Then a report on the insights of the study is presented followed by
a discussion on the findings and suggestions for future work.

RELATED WORK

Tangible User Interfaces

Tangible User Interfaces (TUI) is a concept that was conceived by Hiroshi Ishii and his group at the MIT Media Lab in 1997 [6]. Their vision of tangible bits was introduced based on the argument that humans possess highly developed skills for processing information through haptic interactions with physical objects. However, most of these skills are disregarded in interactions with Graphical User Interfaces (GUI). As a result, TUIs were proposed as an effort to take advantage of such skills for closing the gap between digital information and the physical environment. Ishii continued developing his vision, proposing frameworks describing the structure of TUIs [19], at the same time identifying application domains that included information visualization.

Information Visualization

In parallel, the field of information visualization was evolving with the goal of presenting large quantities of complex information in an intelligible way [17]. Theories, methodologies and design strategies [12] were proposed aiming mainly towards GUIs because of the possibilities of dynamic navigation, searching and filtering that they offer. The field has matured over the years leading to the identification of specific problems [1] from user-centered and technical perspectives. Simultaneously, the importance of senses other than visual has been recognized in information visualization resulting in theories to unify its use [15].

Physical Visualizations

The topic of information visualizations has been studied under the names of “physical representations”, “physical information visualization”, and “tangible visualizations”. However, there is not a clear definition of physical visualizations. Several approaches for presenting information that make use of human natural abilities for understanding the physical environment have been proposed. In this work, the umbrella term physical visualizations is used to refer to visualizations beyond the desktop that are in line with Ishii’s vision of TUI [6].

An approach to a categorization was proposed by Vande Moere presenting a review of a collection of physical visualizations [13]. Six groups were proposed to categorize the levels of physical visualizations: ambient displays, pixel sculptures, object augmentation, wearable visualizations, data sculptures and alternative modalities. By showing these examples, the work intended to demonstrate the advantages of physical abstractions and sensorial stimulations.

The first study comparing physical to graphical visualizations was presented in 2013 [7]. The example of physical 3D bar charts was chosen to compare its efficiency at information retrieval tasks with its on-screen counterparts. The study measured the time that users took to answer questions correctly based on the information presented by the 3D bar charts. The conclusion was that physical 3D bar charts do better than their on-screen versions pointing out that touch seems to be an essential cognitive aid.

Later on Jansen and Dragicicv presented an adapted model of the information visualization pipeline that includes visualizations beyond the desktop [9]. This model was used to describe large-scale visualizations and physical information visualizations. Through case studies, it was demonstrated how the model can be used to describe desktop visualization systems and at the same time wall-sized displays, 3D and shape-changing displays, touch and tangible inputs.

Data physicalizations and data sculptures

Zhao and Vande Moore [23] established the concept of data sculpture and suggested a domain model to describe it. The model identified the four main research areas involved: information visualization, tangible user interfaces, visualization art and interactive art. However, the definition is more focused on the artistic component than in the use as a mean to convey information. In the same work, embodiment in a data sculpture is defined as “the expression of abstract data in physical representation through the process of data mapping” [23]. Data mapping in information visualization is the process of attributing data values to representations with the aid of metaphors.

In parallel, Jansen proposed a definition of embodied display as “Any information display that elicits a stable and robust perception of congruence between the surfaces of the physical display medium itself and the surfaces it is meant to display” [10]. This definition aims to describe the level of data embodiment of a display. In 2015, Jansen et al. presented a working definition for the concept of data physicalization: “a physical artifact whose geometry or material properties encode data” [8]. The definition intends to bridge the gap between traditional fields such as data visualization and TUI focusing on data exploration and analysis.

Ambient displays

Ambient displays are part of Ishii’s vision of TUI [22]. By turning architectural spaces into “interfaces”, they intend to move off information from the screen into the physical environment by using subtle changes in the state of physical matter. This proposal cites inspiration on Weiser’s concept of “calm computing” [21] which defines technology that moves between the periphery and the center of the user’s attention.

Following Weiser’s & Ishii’s visions, several propositions were introduced under the names of “ambient displays”, “peripheral displays” and “notification systems”. In an attempt to unify this concept and create a standard
vocabulary, in 2007 Pousman and Stasko presented a definition of ambient information systems categorizing both GUIs and TUIs based visualizations [14]. These systems display information that is important but not critical, can easily move from the periphery to the focus of attention and back, they focus on tangible representations in the environment and provide subtle changes to reflect updates in information.

According to Vande Moere’s categorization [13] ambient displays constitute the lowest level of physicality of information visualizations and they are positioned in the border line between GUIs and TUIs, depending on the instance some ambient displays are completely screen based. In addition, Vande Moere recognizes the use of physical visualizations through alternative modalities in alarms and remote monitoring [13].

**Visualizations of Bio-data**

Measurement of physiological, biochemical and physical variables from the human body is a process that is becoming pervasive and automatic. Thanks to the inclusion of sensors in wearable devices. Such sensors allow measuring of data that includes heart rate, temperature, galvanic skin response (GSR), muscle activity and motion. In this work, this type of data is referred as bio-data. The key role of information visualization for presenting this type of data was recognized [16]. Relevant approaches to communicate and use bio-data on different application domains are presented below.

With the intention of supporting users in making sense of the relationship between stress and their behavior in everyday life, the project Affective Health proposed a visualization in the form of a spiral [20] to allow users to understand events and changes in stress levels over time. These stress levels were determined by processing galvanic skin response, movement and heart rate of a person. The system presents a contribution by presenting information that is based on bio-data, allowing the user to have a perspective on what has happened to his/her data along a period of time.

Khot et al. [11] reported on the system SweatAtoms. Based on heart rate sensors the system transforms physical activity into 3D printed material objects. The system was evaluated and concluded that the participant’s relationship with physical activity can be affected by physical representations. This project demonstrated the ability of activity sculptures to increase motivation and self-reflection, carrying out a field study that showed the impact of the physical artifacts on the user’s behavior.

**Safety**

Fugini et al. [2] proposed a wearable-based service system to improve safety in workplaces. In their work, the technological features of the system were outlined while recognizing challenges involved in emergencies. These challenges included managing information rapidly, taking effective decisions under emergency situations and rapid judging and reacting to situations. The authors pointed out the critical role of information visualization on solving these aspects and the need for future research in this area.

Another example of a monitoring system based on sensor bio-data is proposed by Gaura et al. [3]. With the aim of increasing safety in bomb disposal missions, a wearable sensor network is proposed. The system provides a visualization for remote monitoring using GUIs. However, the scope of the work does not give much attention to the interface, nor analyses the implications from a data visualization perspective.

These examples highlight the potential of TUI and GUI visualizations of bio-data. Additionally it presents its uses across different domains including safety. However, the task of remote monitoring of bio-data using TUIs is not addressed. The research question that this work aims to answer is: “Can physical visualizations support remote monitoring of bio-data?”

**METHOD**

By definition a probe is “an instrument that is deployed to find out about the unknown to hopefully return with useful or interesting data” [5]. This work intends an exploration of a novel way for presenting bio-data; with this goal in mind and with the purpose of uncovering the unknown, using a probe becomes a suitable method. Technology probes are not early prototypes but tools to determine what kind of technologies would be interesting to develop in the future [5].

A technology probe for presenting real time bio-data is proposed. Options such as orbs, physical bar charts and dolls were considered to convey this information. Dolls were selected since an anthropomorphic figure intrinsically represents a person, while allowing a less abstract mapping of the data. Additionally, the metaphor of a voodoo doll was used. Although generally voodoo dolls have a negative connotation, this concept presents an opportunity to be used as a metaphor by conveying the message of an avatar that is directly related to a person. The probe in this work reverses the concept and uses it in a playful way to signify the embodiment of a person’s current physiological conditions into a physical object. The introduction of playfulness had the aim of encouraging the use of the probe inspired by Gaver’s Ludic design [4].

Technology probes, different from prototypes, should be simple and have a single main function [5]. Heart rate and motion were selected as a light way to remotely monitor a person’s safety; more measurements were taken into account but for the purpose of the probe a subset of the possible physiological variables was extracted. The materials selected for the probe were materials for producing physiological variables was extracted. The selection of colors and signifiers was done having in mind to stay away from a negative connotation. White color
was chosen for the probe in order to be associated with medical and health conditions. Certainly, alarms are an important part of a monitoring system. However, they were left aside in the design of the probe. The inclusion might have reduced the attention dedicated to the doll.

![Figure 1: Reversed Voodoo Doll](image)

The heart rate is represented by pulsating LEDs in the shape of a heart in the chest of the probe combined with a haptic simulation of the heartbeats through vibrations. The heart has a color-coding to signify the condition of the heart rate. A normal heart rate between 60 and 140 beats per minute (bpm) is red matching the background color of the heart. A high heart rate of over 140 bpm is presented as yellow. An extreme situation such as dangerously low heart rate below 50 bpm is presented in a blue color. The motion is represented by changes in intensity of the eyes of the doll using yellow color. This motion is intended to be a representation of the movements tracked by an accelerometer in the wrist of the person represented by the doll. Intense motion in the accelerometer corresponds to a high intensity in the eyes of the doll. No motion corresponds to the eyes switched off.

**Deployment**

One reversed voodoo doll was produced for the study. It was deployed at ABB’s Corporate Research offices in Västerås, Sweden. Six users volunteered to participate. The study was carried out in six different sessions, one with each participant, each session lasted for a day from 10:00am until 5:00pm. During each session, the corresponding participant monitored the doll, the participant was instructed that the probe represented a colleague from the same office. For ethical reasons the participant was aware that no one was going to be at risk during the experience.

Each of the participants was instructed that this person was going to be away from his desk at random times during the day performing daily activities for instance picking up office supplies from other installations, performing laboratory work and testing projects outdoors. The participant was told that the probe could be used to monitor this colleague, with the intention of making him feel safer while performing work activities alone. The participant was given instruction on the signifiers of the probe, telling them that the eyes represented the motion of the person from an accelerometer on the wrist and that the heart represented the heartbeat visually and haptically. No instruction was given regarding the color coding of the heart or the situations that were going to be presented. The participant was asked to take an action in case that something seemed wrong in the probe that could mean the person being monitored was under a potential threat. The action was communicating with the researcher sending an SMS as soon as the danger was perceived.

During the study, the participants were carrying out activities that included sketching, reading reports and emails, teleconferencing, coding and doing online trainings. All of the participants agreed to dedicate a portion of their attention to monitor the doll and reported that the workload for the day allowed them to participate. The participants were free to take coffee breaks, to go to meetings and to choose how much attention they would dedicate to the doll. The participants were instructed about the two hours duration of the doll’s battery. The ages of the participants range from 23 to 35 years old, three females and three males. Four of the participants are currently employed. The remaining two participants have worked at ABB for more than five years. One participant had a background in administration. Two of the participants were HCI researchers. Three of the participants had a technical background in embedded systems.

In order to create scenarios where the person represented by the doll was at risk, the researcher presented situations on the probe’s eyes and heart where the motion and heart rate were too low or too high. During each experience with each participant, the following six situations were presented: **Low activity** associated with the person represented sitting in front of a desk while doing work on a computer. It is shown in the doll by presenting a heart rate between 60 and 80 bpm and motion in the eyes between 10 to 40 percent of the maximum intensity. **Medium activity** associated with the person walking around the office, was represented with a heart rate between 80 and 120 bpm and intensity in the eyes between 40 to 70 percent. **High activity** that represents a person running or carrying heavy items increased gradually from 130 to 180. The intensity of the eyes varied between 70 to 100 percent of the maximum intensity. An accident was represented by the eyes of the doll off during a long period of time. During this time, the heart rate remained normal between 60 and 80 bpm. A stressful situation was represented by showing the eyes of the doll off and an accelerated heart rate of over 120 bpm. A situation of sickness associated with exposure to cold temperatures and hypothermia was represented by having low activity of 30 percent of the maximum intensity and a heart rate below 50 bpm.

During the study, the doll had the same predefined routine for all the participants. Normally, the doll was presenting
information corresponding to low and medium activities. While alternating between these two scenarios it was intended to simulate the behavior of a person that works at an office space. Additionally, during the experience for each participant the following situations were presented: three events of high activity, three stressful situations, two accidents and one sickness event by the end of the experience. After the doll was placed on the participants’ desks, the participants were left to interact independently with the doll as they saw fit. The researcher did not play an active role within the experiment.

**Data Collection**
The participant’s interactions with the probe were recorded placing a camera aiming at the doll in the participant’s desk. The participants were provided with a diary to complement the data collection and to allow them to move the probe from the desk at will. The participants were asked to take notes of the information perceived in the probe, indicating what they thought was happening to the person represented by the doll. Additionally, they were instructed to write their reflections and thoughts about the experience with a focus on the times when they thought the probe was showing a critical situation for the person being monitored. At the end of the experience, a semi-structured interview was performed with each of the participants lasting 30 minutes. The objective of the interview was to raise feelings, concerns and feedback regarding the experience and the probe. During the interview, three main themes were addressed. The usage given to the probe and output modalities, the information perceived and finally the thoughts and concerns sparked by the doll. First, the participants were asked to describe their usage of the probe, specifying the interactions performed and their thoughts and reasons for the particular uses. Second, the participants were requested to describe the situations perceived in the doll while specifying the signals that made them get to particular interpretations. Third, they were asked to reflect on the experience, describing positive and negative feelings.

**Hardware**
The hardware of the reversed voodoo doll consists of an Arduino YUN with integrated WiFi. The heart beat and the eyes use addressable RGB LEDs. The haptic simulation of the heart beat uses a vibration motor. The probe has a battery inside that allows it to run for two hours. The charging is performed wirelessly, hence the doll doesn’t have any wires attached and can be freely removed from the dock, according to the participants will.

**RESULTS**
The researcher gave freedom to the participants on choosing where to place the doll and the charging dock on their desks. The participants adjusted by themselves the physical location of the doll looking for a place where it could be visually accessible while performing their regular activities. The location of choice was next to the screen on their desks, in some cases where the participant had more than one screen the doll was placed next to the screen that the participant used the most.

After finding a place that the participants considered adequate, they attempted to continue their regular work. However, during the first minutes of the experience they reported dedicating a considerable portion of their attention to the probe. The participants reported reduced focus on the main task and concern for what could happen to the person represented by the doll.

“At the beginning I was a little bit stressed, not because it was disturbing but because I was wondering: what if the person is not well? Then I had to look at the doll all the time, but after a while I started forgetting it was there.”

Participant 3

![Figure 2: Probe placed in a participant’s desk](image)

After a brief period of dedicating attention to the probe, the participants gradually shifted the focus of attention from the doll to their work activities while still having the doll in a secondary focus of attention.

**Visual display and information perceived**
Most of the interactions of the participants were done by glancing at the doll. The participants described the changes in the eyes of the doll as hard to perceive and to differentiate from one another. When the participants were asked how many levels of motion they detected, four of the participants reported seeing three levels: no motion, some motion and intense motion. The remaining two participants encountered only two states: no motion and motion. Regarding the visual heartbeat, the participants reported recognizing different levels of heart rate. When the color of the heart turned blue, all of the participants reported perceiving the change. Only three participants reported recognizing a yellow color in the heart. Nevertheless, all of the participants were able to tell situations when there was an increased heart rate.

The participants’ interpretations varied according to the situation presented in the probe. All of the participants recognized situations intended to be interpreted as Low
Activity. This situation is presented as a low intensity in the eyes of the doll and a heart rate between 60 to 80 bpm as described in the method section. The participants associated red color with a normal condition related to the person represented doing work in a computer while sitting.

“I could tell at the beginning he was starting the day, calm. I assumed a red heart was normal” Participant 1

Situations of Medium Activity were also reported, where the doll was showing a more intense light in the eyes and an accelerated heart rate. Although the participants mentioned that, it was hard to tell the difference between different levels of motion. The participants were able to tell that the person was performing some activity with no remarks.

“You can tell the difference from some activity to heavy activity but there is not a clear borderline.” Participant 2

“Regarding the eyes I was a little bit unsure. It was hard to know when was brighter than before.” Participant 5

The participants did not see higher heart rates and a yellow color in the heart as dangerous. When there was motion in the eyes they concluded that the person was exercising or carrying out heavy work, this situation was intended to be interpreted as High Activity. Most of the participants wondered why the person was so active at an office space and reported the situation to the researcher because they thought this was an odd behavior.

In the case when the eyes were off and the heart rate was high, three of the participants associated it with a dangerous situation; this case was intended to be interpreted as Stress. Participant 3 concluded that the person was scared. Participant 5 concluded that the person was under stress. Participant 1 associated the situation with an accident but wasn’t sure about what kind. For participant 4 it didn’t make sense to have this situation, the rest of the participants didn’t report this scenario.

“Maybe he is a bit scared, he is not moving but his heart rate is still high.” Participant 3

The cases intended to convey an Accident presenting a moderate heart rate and no motion in the eyes were not associated with any danger at all. No light in the eyes was associated with the person sleeping or just resting, the meaning perceived by the participants was that the eyes of the person were closed.

“The eyes off looks like he is sleeping” Participant 2

“No light in the eyes looks like his eyes are closed” Participant 5

The blue color was immediately associated with an uncommon situation potentially dangerous and all of the participants quickly reported it to the researcher. This scenario was intended represent a Sickness of the person represented.

“When the heart rate went down it was pretty obvious thanks to the blue heart.” Participant 4

**Physicality and portability**

The physicality of the doll was used at the beginning of the experience when the participants were naturally more curious about a new object on their desks. All of them inspected it, held it and took a closer look while exploring the materiality. After this exploration, most of the time, the probe was placed on the participant’s desk. Consequently the participants were monitoring mainly using the visual and audio output.

Since the probe does not have a numeric visualization of the heart rate, participant 4 tried to discover if the pulse of the person represented was normal by measuring the pulse on the doll, counting the amounts of beats during a period of time while touching the doll as if it was done directly in a person. Participant 3 wanted to discover if her own heart rate was normal and compared it to the heart rate of the doll by touching it and placing her hand on her wrist at the same time.

Participant 5 attended a videoconference on her desk during the study. While participating in the call she was wearing headphones and could not hear the probe. Even though she was able to see the heartbeat in the probe, she recurred to the haptic modality to make sure the heartbeat presented in the doll was still present.

The portability of the doll was exploited in one occasion. Participant 6 was the only one that decided to take the doll away from her desk during a coffee break. The five remaining participants never took the probe away from the desk. The participants were concerned about the portability of the doll, although they were informed that the probe was wireless and had enough battery to run for two hours five of six participants didn’t remove it from their desks.

The participants reported reasons for not carrying it around that included bulkiness of the doll, being afraid of the doll not working due to technological concerns and finally the probe causing distraction when performing tasks away from the desk.

“It was big to take it around, if it was something more discreet...” Participant 2

“I thought about taking it with me but I wasn’t sure from a technological perspective.” Participant 3

“If I take it with me then I have to concentrate on the doll.” Participant 5

**Sound display**

An unexpected behavior reported by all of the participants was how the sound produced by the vibration made them aware of the probe, even when the participants were deeply focused on their regular task not giving attention to the doll they could quickly notice changes of the heart rate thanks to the sound of the heartbeat. This output was a result of the
physical construction of the doll originated in the vibrations of the heartbeat against the case. Although the sound was unintentional in the original design, the participants considered it useful.

“The sound was quite unexpected; I think it was the one thing that made me aware of the doll. It wasn’t annoying.” Participant 2

“I think the sound is helpful because you don’t have to look at the doll all the time.” Participant 6

Participant 1 had a loud laptop and decided to move the doll closer to him in order to listen to it. He also reported that during the study, there was a point when there were people in the corridor making noise and he decided to close the door of his office to be able to listen to the doll.

**Attachment and engagement**

Due to the instruction given by the researcher of monitoring over a remote person, the participants informed being concerned about the conditions of this person. Therefore, they wanted to dedicate attention to the probe in order to report potentially dangerous situations. The participants reported a sense of guilt when they were not able to monitor for reasons such as leaving the office or focusing on their regular tasks.

“I feel a little bit guilty when I forget about this poor guy.” Participant 3

“I felt a bit bad when I left it here to talk to other people.” Participant 5

Participants 1, 2, 3 and 5 reported a concern for the periods where they were not looking at the doll. When they refocused their attention to the probe, they wondered if they missed some event while distracted.

“I wasn’t sure if something had happened while I was away” Participant 2

“When I went away and then came back I couldn’t see if something had happened, I don’t know about the history.” Participant 5

Furthermore, the participants expressed a desire on being able to take actions when critical situations were presented such as being able to see more information about the person represented by the doll and having the means to quickly communicate and check on the person.

“I can feel the responsibility; see that something is wrong with the person, however there is not much I can do.” Participant 1

“I get worried but I would like to be sure something is wrong and how can I help” Participant 5

The thoughts sparked by the probe were of fun and playfulness. Participant 4, 5 and 6 associated the probe with a toy. Participants 3 pointed out the resemblance of the doll with a baby that needs to be taken care of.

**DISCUSSION**

The results present how a group of six participants reacted to monitoring bio-data using a technology probe. The results show the use given by the participants’ to the probe and the encountered interactions and interpretations. This work intends to determine if the direction of physical visualizations supports monitoring of bio-data.

**Physicality and embodiment**

The reversed voodoo doll presented in this work attempted to achieve a high degree of physicality. However, the amount of information that could be perceived by haptic interactions was limited, and the users manifested concerns regarding technology and size of the object. As a result, the amount of interactions performed with senses other than visual was reduced.

The majority of interactions were performed by glancing at the probe, while the participants switched the focus of attention between a main task and the doll. This behavior corresponds to an ambient display. In Vande Moere’s categorization [13] an ambient display represents the lowest degree of physicality. Nevertheless, ambient displays are still part of Ishii’s vision of TUI [22] pushing information into the physical world. The responses and interpretations from the users suggest that the reversed voodoo doll served as a means to transmit information in its own right. In spite of the reduced amount of haptic interactions, the reversed voodoo doll occupied a space in the physical world while embodying data. This behavior was in line with Jansen’s definition of embodied displays [10], having a strong congruence between the surface it is meant to display and the physical medium itself.

**Metaphors and playfulness**

The results suggest that the use of an anthropomorphic object to embody information had the positive impact expected. The participants described the experience as fun and reported associating the probe with a toy. Gaver has explored this sense of playfulness [4] reporting that it is an essential aid for increasing engagement in the usage of technology. The sense of attachment reported by the participants can be associated with the engagement induced by the doll. By making the experience fun and using an object that resembles a living entity, a sense of responsibility seems to have been induced in the participants. The results of this study suggest that the introduction of Gaver’s Ludic Design encouraged the users’ involvement in the experience. However, it can have side effects reducing the importance of the situation.

**Data mapping and multimodality**

The level of data transformation and processing applied to the data in both cases heart rate and motion was low by design. The heartbeat’s direct visual mapping into a shape of a heart aided by audio and haptic displays seems to have been effective in conveying information about the heart rate. Nevertheless, as reported by the participants it was hard to draw conclusions on the frequency of the heartbeat,
by itself it didn’t convey any meaning. The color coding was useful for signifying unusual situations and levels of heart rate. It can be argued that the selection of red for a normal situation was against normal conventions of emergencies and it could have caused misinterpretations. However, the perception of the participants’ shows that in the context that was set, red color was associated with normal and blue color with abnormal situations.

The audio and haptic displays were used by the participants in specific situations. These modalities complemented each other validating Roberts and Walker’s proposition [15] of unifying senses in information visualization. However, the use of the audio display was counter intuitive. It wasn’t used as an alarm but as an indicator of absence of emergencies. It allowed the participants to occupy their visual sense in the main task while still being aware of changes in the heartbeat.

The motion had a more abstract encoding that was hard to perceive by the users. Different levels of activity were difficult to notice, leading to a reduced amount of perceived levels of motion. Although ambient light was not a controlled factor in the study, it could have affected the perception of the users and contributed to the differences in the interpretations. Furthermore, the participants did not perceive presenting the eyes of the doll off as a potentially danger. Instead, it was perceived as if the eyes of the doll were closed meaning that the person was sleeping. This indicates that levels of intensity had drawbacks for conveying information in a physical object and other techniques such as color coding should be used. Based on the results it can be suggested that traditional information visualization techniques such as color mapping can be applied in physical visualizations, however it is necessary to take in to account technological constraints and ambient lights that can affect the interpretation of the user.

**Bio-data monitoring**

The participants were concerned regarding the attention that they needed to dedicate to the probe. From this two possible scenarios can be extracted for a monitoring application setting: the first scenario is the prevention of emergency situations. In this case the information presented in the visualization is not critical. While displaying this information is not necessary to interrupt the main task of the user, the information is always available in a secondary focus of attention. In this scenario the probe has the behavior of an ambient information system proposed by Pousman [14]. The second scenario are emergency situations where it’s clear the need of alarms that interrupt the user’s main task. Although they were left aside in the design of the probe, the usage made evident the need of including them in a monitoring system. According to Pousman [14] the inclusion of alarms steers away from the definition of an ambient information system since they are not subtle and demand the users attention.

Certainly, the results show that the inclusion of more physiological and environmental variables is necessary in order to have more insights about a person’s conditions. A higher level of data processing and transformation is required for the design of a monitoring system to be reliable and provide enough information.

The probe proposed in this work was displaying only real time data. As a result, the participants manifested their concern about the periods when they couldn’t monitor the doll. In other words, the participants were interested in seeing information that would help them to understand what had happened previously. This users’ desire was addressed by Vaara et al. [20] proposing a visualization that allows to understand bio-data that varies over time, however it relies on a GUI having the advantage of dynamic navigation. In the physical world an example are Khot’s data sculptures [11] that produce 3D printed artifacts based on heart rate activity variation over time. However, these physical visualizations are static, once they are 3D printed they don’t support any updates. There is a challenge for visualizations such as the probe proposed in this work for achieving both, being able to display dynamic data and at the same time, providing insights such as a perspective of variation over time. As pointed out by Jansen et al. [8] this challenge relies in the fact that physical visualizations are limited by available technologies. This study agrees with Jansen et al.’s suggestion. In their work it’s proposed that physical visualizations is a promising application domain for novel technologies such as shape-changing materials, deformable visual displays and shape-memory alloys [8]. The use of such materials can allow visualizations to display dynamic data and at the same time insights such as dynamic navigation.

**Problems**

The participants’ interpretations differed from one another. One reason suggested to explain these differences in the participant’s conclusions is that the interpretations were subject to participants’ prior knowledge. This problem arose in the usage of the technology probe proposed in this work. However, the problem has been already identified as one of the main problems in the field of information visualization [1]. This study confirms previous findings that suggest that prior knowledge remains one of the most important challenges to solve in information visualization. For this reason, designers should make decisions taking into account the level of knowledge of the user.

**Limitations**

The reversed voodoo doll technology probe was used for an exploration of the unknown. The users of the system were stimulated by providing them with the task of monitoring the doll. The results quickly reveal insights about the usage of a physical visualization for display of dynamic bio-data, the interpretation of the signals and the acceptance of the interactions. However, the results don’t allow conclusions about the usage in an industrial safety setting. Access to a
different set of users for instance safety supervisors would have allowed to gather information about these particular users’ needs, allowing to elaborate on the topic of safety monitoring.

Technology probes are a fruitful method to evoke rich enough experiences but rather time consuming. A technology probe needs a shorter design process with a different purpose from a prototype. The use of technology probes in information visualization has been reduced. Methods such as system design and user centered design are traditionally used in this field. However, as information visualizations merge into the physical world through interactive objects, methods such as technology probes provide a way to gather data from the users in a real world context. Hence, designers are allowed to make choices on what data is relevant in specific situations.

The use of complementary data collection methods is frequent when using technology probes. For instance, they allow the usage of interviews and workshops before and after the studies [5]. In this work the combination of multiple methods was successful. In the case of the recordings, due to the low amount of physical interactions, the data gathered through this method was reduced. However, this was compensated by the diaries and interviews. Moreover, a richer data gathering would have been possible aided by technology. For instance including accelerometer and touch sensor data in the probe to measure the amount and duration of haptic interactions. These data collection methods would have allowed a quantitative study. However, for the objectives of the exploration of this work, external data collection provided enough information to answer the research question.

Future Work
The main goal of this work was to identify a new application domain for physical visualizations. The implemented probe demonstrated the potential of a physical object to present bio-data. Nevertheless, it is only the initial step into a highly complex and diverse design and research space. The following areas for further research are suggested as a result of this work:

A comparison between physical visualizations and traditional screen based visualizations is necessary, in order to evaluate the performance on information retrieval tasks in a monitoring setting. Further studies are necessary to address how the level of engagement is affected by time of usage in ambient displays and data sculptures. Additionally, it is necessary to explore how an observer will perform when having more than one person to monitor. In the design of a system that uses physical visualizations to monitor safety, it is necessary to explore the inclusion of other physiological variables and to apply a higher processing of data to have more insights. From a social perspective it is necessary to investigate the interactions between the observer and the observed, this work focused on the feelings and concerns of the observer. It is necessary to investigate user experience issues involved from the perspective of the person being monitored. For instance, concerns regarding privacy & increased control. Finally, interaction between observers where they exchange information and experiences remains to be studied. Since this study was carried out using one doll. It is still necessary to investigate how social interactions between multiple observers, each one monitoring a doll would affect the results and interpretations.

Even though the level of physicality reached was low, the results suggest the potential of physical visualization in related application domains. The exploration can continue having in mind applications such as monitoring of the elderly or infants.

CONCLUSIONS
The goal of this work was to investigate if physical visualizations support remote monitoring of bio-data. The scenario of safety was used to test this approach. A technology probe using a physical anthropomorphic object was proposed. This object was embodied with bio-data in order to represent a remote person being monitored using the metaphor of a reversed voodoo doll.

The results and the usage indicate that the level of physicality achieved by the reversed voodoo doll was low. However, the results suggest that the data mapping to the object’s body parts was effective for conveying meaning. Additionally, the color coding was an essential aid in adding significance to the probe. It can be suggested to follow traditional data visualization color mappings taking into account technological limitations. The results confirm that the use of multiple modalities in physical visualizations offers an opportunity to present information in situated contexts in the real world. The inclusion of playfulness in the design seems to have been of substantial aid on encouraging the usage of the probe. However, the side effects of this in a safety scenario remain to be studied.

The responses and interpretations from the users suggest that the physical visualization proposed in this work served as a means in its own right to transmit information for monitoring of bio-data. This study is the first step in the exploration of a new application domain for physical visualizations. However, it demonstrates that physical objects can be used for remote monitoring of bio-data.

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REFERENCES


