# Is my Phone Alive? A Large-Scale Study of Shape Change in Handheld Devices Using Videos

**Esben W. Pedersen**
Department of Computer Science
University of Copenhagen
esbenwp@diku.dk

**Sriram Subramanian**
Department of Computer Science
University of Bristol
sriram@cs.bris.ac.uk

**Kasper Hornbæk**
Department of Computer Science
University of Copenhagen
kash@diku.dk

## ABSTRACT

Shape-changing handheld devices are emerging as research prototypes, but it is unclear how users perceive them and which experiences they engender. The little data we have on user experience is from single prototypes, only covering a small part of the possibilities in shape change. We produce 51 videos of a shape-changing handheld device by systematically varying seven parameters of shape change. In a crowd-sourced study, 187 participants watched the videos and described their experiences using rating scales and free text. We find significant and large differences among parameters of shape change. Shapes that have previously been used for notifications were rated the least urgent; the degree of shape change was found to impact experience more than type of shape change. The experience of shape change was surprisingly complex: hedonic quality were inversely related to urgency, and some shapes were perceived as ugly, yet useful. We discuss how to advance models of shape change and improve research on the experience of shape change.

## ACM Classification Keywords

H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces—Haptic I/O, Input Devices and strategies, Interaction styles.

## General Terms

Experimentation; Human Factor; Measurement

## Author Keywords

Shape-changing Interfaces; Shape Displays; Organic User Interfaces; Actuated Interfaces

## INTRODUCTION

Handheld devices have become orders of magnitude smaller, more powerful, and higher-resolution compared to a few decades ago. Such devices used to be static in physical appearance, but that is changing. Shape-changing handheld devices are being discussed in workshops [1] and as industrial concepts (e.g., Nokia Kinetic [21]), and realized as commercial products (e.g., www.tactustechnology.com) or research prototypes (e.g., [8, 15, 32]). Examples of the latter include Morphees [32], a series of shape-changing handheld devices that are self-actuated and can adapt their shapes to offer better

affordances, and Animated Mobiles [17], a device that reacts to the user's hand by moving so as to show affection or rejection. These devices are instances of what may be called shape-changing interfaces [7, 31], or organic interfaces [9].

Our current understanding of shape-changing handheld devices mostly rests on prototypes such as those mentioned above. Two important trends of research try to move beyond prototypes. One trend is to formulate more general models of shape change [30–32]. The paper on Morphees [32], for instance, listed 10 parameters of shape change and illustrated how they may be varied to produce markedly different handheld devices. Such models may be used to characterize shape-changing interfaces and to generate ideas for new, principled different prototypes. Another trend is to evaluate the user experience of shape-changing handheld devices. Hemmert et al. [15] showed that users could accurately detect changes in the angle of the backplate of a shape-changing mobile and that its attractiveness was rated highly. Not only do such evaluations help assess prototypes, they also give a sense of the type of experiences that shape-changing handheld devices may engender.

However, these two trends – modeling shape change and studying user experience – are hard to bridge. Models cannot be directly evaluated; when they are used to create prototypes, evaluations of those prototypes are rarely related back to parameters of the model. Whereas earlier models identified parameters such as curvature and amplitude (e.g., [32]), for instance, they did not suggest what users would find acceptable and useful ranges. Conversely, all evaluations of curvature that we are aware of are done on one design instance, which makes it difficult to obtain any general understanding of how different parameters of shape change are perceived and how they affect the user experience. The present paper attempts to bridge these trends.

We systematically vary the parameters in models of shape change to produce 51 videos of a shape-changing handheld device. We describe users' reactions to those videos using several measures and open-ended questions about user experience. The differences in experience that we find are then related back to parameters of the models used to create the videos. The key assumption of this approach is that users' reactions to videos capture at least some of how they would perceive actual devices. This assumption has been used both in HCI (e.g., in studying interactivity [27]), and outside (e.g., in studying physical designs [20], how intention behind actions are understood [18], and social robotics [4]).

We make three contributions. First, we describe experience over a wide range of shape parameters, rather than just with a point design or over one parameter of shape change. Second, we describe some boundaries of known shape models for handheld devices. Third, we show how the relation between model and experience may be used to reason about how a design may be changed to change experience. These contributions are primarily oriented toward researchers in shape-changing handheld devices, but have implications for designers of such devices as well.

## RELATED WORK

We draw on three areas of research related to shape-changing handheld devices. First, we review papers describing prototypes of shape-changing handheld devices, then we discuss models of shape change, and finally we review user evaluations of shape-changing handheld devices.

### Shape-changing Handheld Devices

Shape-changing handheld devices are a class of shape-changing interfaces with the ability to physically displace their surface through self-actuation, and which are small enough to fit in the palm of the user. Such interfaces may be divided into two groups: (a) conceptual prototypes [15, 16, 32], and (b) more developed prototypes that support both actuation and graphical output [2, 10]. In addition to these two categories, deformable, non-actuated handheld devices exist [25, 34], but are outside the scope of this paper.

The first group include Shape-Changing Mobiles by Hemmert et al. [15], a transparent, phone-sized box that can move the top and bottom half of the backplate independently to create both angular actuation and thickness actuation. This conceptual prototype was motivated by a desire to improve ergonomics and to provide navigational cues such as pointing towards a destination to support navigation. Dynamic Knobs [16] uses small bumps on the side of the device to notify the user of missed calls. The numbers of bumps indicate the number of missed calls and can both be seen and felt. The Morphee prototypes [32] explored different ways of designing shape-changing handheld devices and showed how different materials and actuation methods create devices with different affordances and shape-changing properties.

The second group of shape-changing handheld devices are the ones that support both actuation and graphical output. More-Phone [10] is a thin prototype of a phone that uses Shape-Memory Alloys (SMA) to bend the corners of its flexible e-ink display or bend the entire device. It does so to notify users about incoming calls, text messages, etc. Tilt Display [2] is a self-actuated handheld device with a display made of several individual displays, each of which can tilt along one or more axes and move up and down. This enables Tilt Display to show graphical content, like maps and videos, in 3D.

### Models of Shape and Shape Change

The purpose of models of shape change is to generalize changes in shape and break them down into a set of shape primitives. These models help characterize similarities and differences among devices, inspire new designs, and provide a common vocabulary for researchers on shape change. The first model for shape change was presented by Parkes and Ishii [30]. In this model the authors focus on deconstructing shape changes into material properties (e.g., *skeletal*, *layered*) and mechanical properties (e.g., *hinge*, *fan*, *aperture*). They use these properties to describe the kinetic capabilities of devices.

In a review of 44 papers on shape-changing interfaces, Rasmussen et al. [31] distilled eight types of change occurring in shape-changing interfaces. Compared to the kinetic properties of Parkes and Ishii's model [30], the types of shape change found in the model of Rasmussen et al. are more high-level. The eight types of shape change are divided into changes that are topologically equivalent (*orientation*, *form*, *volume*, *texture*, *viscosity*, and *spatiality*) and not topologically equivalent (*adding/subtracting* and *permeability*).

Focusing on shape-changing surfaces, Roudaut et al. [32] presented a model with ten features that describe and help compare the deformation capabilities of shape-changing surfaces. The ten features are *area*, *granularity*, *porosity*, *curvature*, *amplitude*, *zero-crossing*, *closure*, *stretchability*, *strength*, and *speed*. The model, which is based on Non-uniform Rational B-splines, provides a classification of existing devices and a tool to compute specific values for the parameters for any shape-changing surface.

The models mentioned above all help clarify the parameters of shape change. However, they provide little understanding of how the various parameters affect the user's experience.

### Evaluations of Shape-changing Handheld Devices

Research in shape-changing handheld devices has primarily been technology-driven and focused on exploring the design possibilities enabled by the advent of shape-changing materials. But this is starting to change. Researchers have begun doing empirical studies of shape-changing devices to understand how they affect user experience. A focus-group study of the Tilt Display [2] found that participants compared visual imagery in this display to a 3D image and found that movement of the display conveyed additional information.

Two studies have investigated the use of shape change in mobile phones to express emotion and intention. Hemmert et al. studied user reactions to a phone-sized transparent box that responded to the nearing hand of the user with five postures [17]. Their results show that, even though the device had no animal-like characteristics, participants tended to explain its behavior by using animal metaphors. The results also showed that the postures were interpreted inconsistently among participants and that more systematic evaluation is needed. The capability of shape change to convey emotions is supported by Dawson et al. in a study of DEVA [8]. DEVA is a gesturing phone that mimics breathing, crawling, and shivering. The evaluation of this prototype showed that shape changes in handheld devices are capable of expressing emotions of both valance and arousal.

A recent study of the MorePhone by Gomes et al. [10] focused on the use of shape change to display notifications. In a study with 14 participants, the authors investigated which

events participants associated with different shape changes (i.e., fullscreen bend and corner bend) and how urgent participants perceived the shape notifications. Fullscreen bend was perceived as significantly more urgent than corner bends.

The above evaluations have provided many insights into user experience. However, the number of studies is limited and they often only evaluate one design instance. In addition, there is no link between those evaluations and more general models of shape change like those mentioned above.

## OVERVIEW OF STUDY
Based on the review of related work, we want to systematically vary shape change to produce videos of shape-changing handheld devices. Using these videos we want to capture users' reactions to shape change by collecting user experience measures and answers to open-ended questions. We describe the study to do so in two parts. *Part 1* describes how the 51 videos that form the basis of our study were generated. *Part 2* describes the details of the empirical study.

## PART 1: DESIGN OF VIDEOS
A key decision in our study is the videos presented to participants. From research on video prototyping, we know that the narrative and the context in which a technology is portrayed affect the intellectual and emotional responses elicited [29]. It is thus important to consider carefully how to represent the shape-changing handheld device, and how to communicate the user interaction and the device's response. Four decisions are involved in generating the videos: (a) the shape-changing handheld device shown, (b) how it is rendered, (c) which use scenarios it is shown in, and (d) which parameters of shape it changes. In the following we will describe our design choices. The movie accompanying this paper shows examples of the videos used in the study.

### Shape-changing Handheld Device
The videos in our study use the smartphone shown in Figure 1. To make it readily visible that it is a smartphone, the size of the device and the aspect ratio of its screen is similar to current consumer models. The smartphone measures 160 x 90 mm and has a 6.9" display. This size is comparable with larger smartphones like the HUAWEI Ascend Mate and research prototypes like MorePhone [10].

The thickness of a device is known to be an important factor when users seek to guess the interactions afforded by shape-changing handheld devices [25]. We wanted a phone that signaled deformability and flexibility. Consequently, we chose a thickness of only 4 mm. This is thinner than current smartphones, but comparable to research prototypes [10, 25, 32].

### Rendering Style
Research on video prototyping suggests that the responses generated by videos are influenced by whether a low fidelity prototype or a high fidelity prototypes is used [28]. Lo-fi prototypes generate more high-level comments, whereas comments on hi-fi prototypes tend to be less general and focus more on specifics (e.g., placement of buttons).
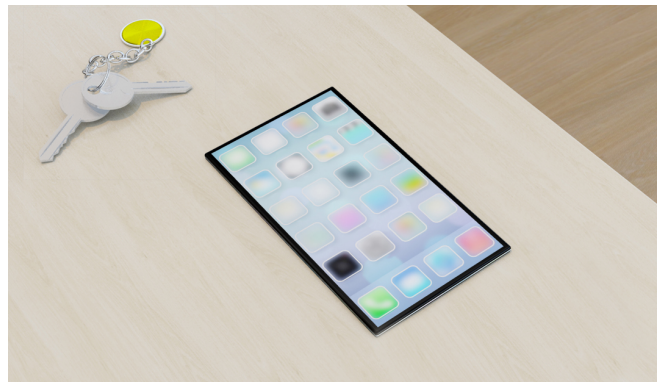


Figure 1. The smartphone shown in the videos. The phone measure 160x90x4 mm and has a 6.9" screen.

To find the best compromise between abstraction and detail, we tested three ways of rendering the smartphone and surroundings: A realistically rendering (Figure 2a), a sketchy rendering that made the animation look hand-drawn (Figure 2b), and a hybrid version with sketchy surroundings and a realistically rendered smartphone (Figure 2c). We pilot tested the rendering styles in an online video survey with 54 participants recruited from Amazon Mechanical Turk. 79.6% of participants preferred the realistic rendering style, 16.7% liked the mixed style the best, and only 3.7% preferred the sketchy rendering style. A typical argument for this preference was that *"the realistic rendering made it easier to think of it as me using the phone"*. As a consequence, we chose the realistic rendering style for the videos in the main study.

### Use Scenarios
We find it highly likely that the use scenarios shown in the video clips will influence how participants react to shape changes. Whereas an increase in area might be practical when browsing, it may be unacceptable for displaying a notification. We therefore included two different use scenarios. The two use scenarios are explained below and are illustrated in Figure 3 with curvature as shape parameter. Although many other use scenarios could be imagined (see for instance other types of interaction in Rasmussen et al. [31]) – and many variations within the above types are possible – we wanted to restrict the number to keep down the total number of videos.

*Notification*
In the *notification* use scenario the smartphone is shown lying on a table with the screen turned off. Its display turns on as a
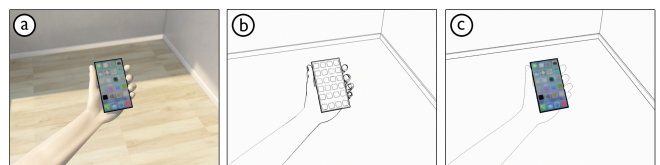


Figure 2. The three tested rendering styles of the device and surroundings: A realistically rendering (a), a sketchy rendering that made the animation look hand-drawn (b), and a hybrid version (c).
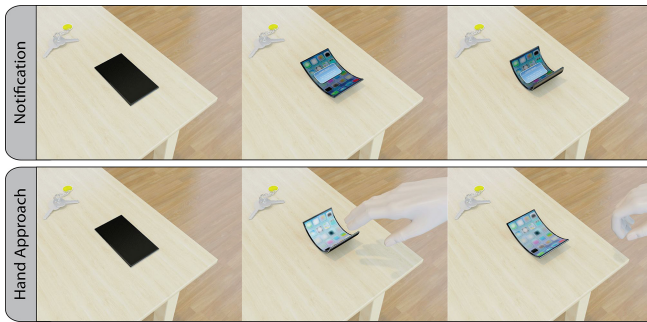
**Figure 3. The two use scenarios investigated in the study: displaying a notification (top), and showing a reaction to a hand that approaches the smartphone (bottom).**

notification is received and the smartphone changes shape to physically notify the user. We included this use scenario because shape change has previously been purposed as an ambient and expressive way of displaying information [6, 22, 31], and because the literature contains several hypotheses about how shape change may affect users' sense of urgency [10].

*Hand Approach*

In the *hand approach* use scenario, the phone is again shown lying on a table with the screen turned off. The hand of a user approaches the phone as if to grab it, and the smartphone reacts autonomously to the approaching hand by changing shape and turning on the screen. The user stops moving the hand for one second before removing the hand quickly. The phone reacts by changing its shape to the initial state (i.e., flat screen, turned off). We included this use scenario to investigate the use of shape change to portray emotions and intention. This is a frequent purpose of using shape change [8, 23, 35] and one that has recently been investigated with shape-changing handheld devices (e.g., [8, 17]).

**Parameters of Shape Change Manipulated**

To determine which shape parameters to change, we compared the available models of shape change [30–32], and found that the model of Roudaut et al. was the most suitable for generating shape changes on flat surfaces. Because participants can only observe shape changes visually in our study, and not feel or interact with the device, we only consider manipulating visual parameters from the model. We therefore distilled the 10 parameters of shape change to the following five: *Area*, *Curvature*, *Amplitude*, *Zero-crossing* and *Speed*. *Porosity, stretchability*, and *strength* are inherently tactile and thus hard to evaluate using video. In the case of shape-changing handheld devices, we can merge *closure* with *curvature* as they enable similar manipulations (i.e., curving the display to form an arc).

In this section we determine a low, medium, and high level of shape change for each of the five parameters. Where possible, we set the level based on the capabilities of existing shape-changing handheld devices. For the parameters of shape change that have not yet been explored in handheld devices, we have broadened our scope to include all shape-changing interfaces in order to determine suitable levels.

**Area** corresponds to the ability of a device to change its surface area. The only shape-changing handheld devices that change their area are the Shape-Changing Mobiles by Hemmert et al. [15]. By raising several levers an area increase of 3x is achieved in order to provide better form factor and navigational cues. Though not a mobile phone, the Inflatable Mouse is also capable of increasing its area by 5x by inflating a ballon inside the mouse.

Because few area-changing handheld devices exist, we have set the low increase in area as 1.5x ourselves. 3x is used as a medium increase (similar to [15]), and 5x is used as a high increase (similar to Inflatable Mouse [23]).

**Curvature** corresponds to the ability of the device to change the curviness of its surface. Curvature is computed by measuring the angle between 3 consecutive control points [32]. For example, MorePhone [10] curved a thin, e-ink display to indicate notifications. Its range goes from from flat (curvature 0) to a curvature of $-3\pi/5$ curvature. Other prototypes use a larger range. Morphee-forged [32] can change from the shape of a convex semicircle (curvature $\pi/2$) to a concave semicircle (curvature $-\pi/2$) using home-educated shape-memory alloy (SMA).

We use $-\pi/2$ (concave semicircle) as low curvature, $-3\pi/5$ as medium curvature (similar to MorePhone), and $\pi/2$ (convex semicircle) as high curvature.

**Amplitude** corresponds to the range of displacement of a point on the surface. It is calculated as the distance between the rest position of a point and the actuated position. MorePhone [10] and Hemmert's Shape-Changing Mobiles [15] can perform shape changes with an amplitude of 15 mm, whereas TiltDisplay has a maximum amplitude of 20 mm [2]. Of the hand-held devices, Morphee-motor [32] offer the largest amplitude of 60 mm.

Consequently, we used the vales 15 mm, 20 mm, and 60mm as low, medium, and high in our studies.

**Zero crossing** describes the capability of a shape to have wave-like patterns. It is calculated as the number of sign-changes between each pair of consecutive angles across the surface. The only shape-changing handheld device that is capable of creating wave-like patterns is the Morphee-couture [32], which can create 3 zero-crossings. To find interfaces capable of producing more zero-croossing, we must include larger devices with more actuators. Project FEELEX [19] is capable of creating 8 zero-crossings, whereas Relief [26] is capable of 14 zero-crossings.

In our study we use 3 as low number of zero-crossings (similar to Morphee-couture [32]), 8 as medium (similar to FEELEX [19]), and 14 as high (similar to Relief [26]).

**Speed** is defined as the minimum time required to move a control point from 0 to max. Many shape-changing hand-held devices actuate using SMA that offer an organic, albeit slow change. MorePhone [10] moves at a speed of 15mm/sec, and Morphee-couture [32] moves at a speed of 13mm/sec. Motors allow for faster actuation but may result in more bulky prototypes. TiltDisplay [2] reports a speed of 20mm/sec, whereas the Shape-Changing Mobile

by Hemmert et al. [15] move with a speed of 53mm/sec (speed was not specified in the paper, but calculated from the video of the prototype).

In our study we use 13mm/sec as low speed (representing the SMA-based prototypes) and 53mm/sec as high speed (representing the motor-based prototypes). To study speed, we cross it with all other parameters. We restrict speed to only two levels, in order to keep down the total number of videos. Speed is not used in the *hand approach* use scenario, as the speed of shape change in this use scenario is determined by the speed of the approaching hand.

In addition to the 5 parameters above, we included two specific instances of shape change, tapering and corner bend, that have previously been studied empirically [10, 17]. We do this in order to be able to compare our results to studies that used physical handheld devices.

**Tapering** is created by diminishing or reducing the thickness towards one end. This type of shape change, which is an instance of area change, was studied by Hemmert et al. [17] as a means of showing affection and aversion in a physical manner. The handheld device used in Hemmert's study

performed 18 mm tapering away from and towards the user. We use these levels in our study.

**Corner bend** is created by bending the corner of the phone upwards. This type of shape change is an instance of curvature change and was recently studied by Gomes et al. [10] as a means creating physical notifications on a shape-changing mobile phone. They used 1-, 2-, and 3-corner bend with a height of 15 mm. We use the same number of corner bends in our study.

## PART 2: EMPIRICAL STUDY

The videos described above allow us to assess users' experience of and reactions to seven parameters of shape change in two use scenarios. Experiences and reactions were obtained through crowd-sourcing the viewing and rating of videos on Amazon Mechanical Turk. Earlier work suggests that crowd-sourced evaluations yield similar results to laboratory studies [13, 24]. As noted, the empirical study has as premise that users react to and experience videos in a manner that can inform us about real use; this premise has also been assumed in much other work (e.g., [20, 27]).

### Design

The study has two independent variables: shape parameters and use scenario. We varied shape parameters within subjects, and use scenario between subjects. Had we used a pure within-subjects design, each participant would have to rate many videos (a tedious and potentially unreliable task). Participants assessed one video at a time: 34 videos for the *notification* use scenario, 17 videos for the *hand approach* use scenario.

### Dependent Variables and Open-ended Reponses

The main data collected were dependent variables about the experience and reactions to videos. For all videos we obtained a measure of *hedonic* and *pragmatic quality* using an eight-item abridged version of the AttrakDiff2 questionnaire [12]. AttrackDiff2 is a widely validated questionnaire on user experience that separates hedonic quality (e.g., tacky/stylish) from pragmatic quality (e.g., unpredictable/predictable). Finally, we obtained measures of *goodness* and *beauty*, also based on earlier work on user experience [11]. Goodness was measured as a seven-point semantic differential from bad to good; beauty as a differential from ugly to beautiful. These questions are supposed to capture an overall, evaluative assessment of the experience.

In addition to these general questions, we asked questions specific for each use scenario. These questions were based on earlier work. For the *notification* use scenario, we asked participants about *urgency*, which was measured as agreement on a five-step Likert scale with the following statement *"This shape indicates something urgent has happened that requires my immediate attention"* (as in [10]). Participants were also asked *"How would you respond to the message?"* and could answer *"attend to it"* or *"dismiss it"*.

For the *hand approach* use scenario, we obtained the following measures. We asked participants to *"describe what*
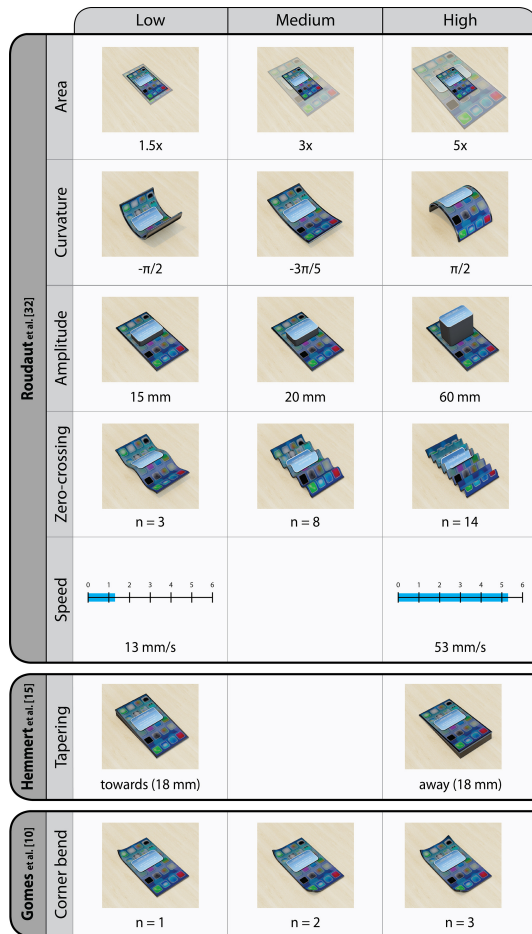


**Figure 4. Seven parameters of shape change with two to three levels per parameter. Five parameters came from Roudaut et al. [32], one from Hemmert et al. [15], and one from Gomes et al. [10].**

*you just saw"*. This question was intended to gauge participants' interpretation of the videos; it is similar to questions asked about MorePhone [10] and in classic experiments on the interpretation of visual scenes [14]. *Animacy* was rated using six items taken from research in social robotics [4]. Items were rated on a 10-point scale and included Mechanical/Organic and Apathetic/Responsive. The *hand approach* use scenario has been linked to particular emotional responses [8]. Therefore we asked participants about *valence* and *arousal* using the self-assessment mannequin, SAM [5]. SAM has been used in user experience research [3] and to study shape change [8].

**Participants**
We recruited participants through Amazon Mechanical Turk. Across tasks, 200 participants started watching and rating videos. Three verification videos were included among the other videos. In each of the verification videos one notable detail changed, and participants were required to textually describe the difference. Using these questions we excluded 2 participants for giving too few details in answers and for repeating earlier answers, 5 participants were removed because they completed the study too fast ($<15$ min), and 6 participants were removed because they indicated a non-optimal video playback. That leaves 187 participants.

The majority of participants were US residents (99.5%). The remaining 0.5% came from Brazil. 51% identified as men, and 49% as women. Participants ranged in age from 18 to 66 ($M = 31.0, SD = 9.7$). 56.4% of participants worked, 18.1% studied, and 25.5% were unemployed. 84% of participants had attended or graduated from college. Participants received 4 US dollars for completing the questionnaire. This corresponds to an hourly salary of 7.2 US dollars, given the average completion time of 33 minutes.

**Procedure**
Before participants started to assess videos, they viewed an instructional video that introduced them to the functionality of the website and explained the purpose of the study. Participants then viewed the videos one at a time in random order. Videos were shown at 640x480 pixel resolution with 1 mbit/s video encoding. If participants shifted away from the browser or attempted to fast-forward the video, it stopped. Only after having viewed the video uninterruptedly, participants could answer the questions shown next to the video. Upon completion, participants were debriefed and given a link for compensation.

**RESULTS**
In this section we report on the results of the two use scenarios. With the *notification* use scenario, we focus our analysis on the scales of user experience as well as urgency and the willingness to attend to a notification. With the *hand approach* use scenario we focus on participants' emotional responses, scales of animacy, and the open ended questions. All scales showed good internal consistency with Cronbach $\alpha$s ranging from .79 to .96. Thus we merge the individual measures and treat hedonic quality, pragmatic quality, and animacy as single scales.

**Notification Use Scenario**
Table 1 summarizes the results for the *notification* use scenario. In the following, we investigate the effects of shape, level of change, and speed individually. In our analysis, we highlight the results for Corner Bend as this shape change has previously been used and studied for shape notifications [10].

*Effects of Shape*
A MANOVA found significant differences among shapes (Wilks' lambda = .372, $F_{30,1842} = 14.911, p < .001$) with no interaction effects. Individual ANOVAs showed that shape significantly affected all the six scales ($F$s between 7.69 and 95.9, all $p$s below .001). Next, we analyze these effects in turn. We give the effect size ($\eta^2$) for the above mentioned $F$-tests when relevant; significant results mean Bonferroni-corrected post-hoc tests.

Shape had a large effect on pragmatic quality ($\eta^2 = .138$). Recall that pragmatic quality is made up by the qualities *structured*, *practical*, *predictabe*, and *simple*. Tapering was rated highest on pragmatic quality ($M = 4.85$), whereas participants scored Zero Crossing significantly lower than all other shapes ($M = 3.96$). Corner Bend was rated second lowest on pragmatic quality ($M = 4.48$).

Shape also affected hedonic quality, though not as strongly ($\eta^2 = .113$). Hedonic quality encompasses the qualities *captivating*, *stylish*, *premium*, and *creative*. Zero Crossing, which scored the lowest on pragmatic quality, was rated the highest of all shapes on hedonic quality ($M = 5.17$) – significantly higher than Area, Corner Bend, and Tapering. Likewise, Tapering was rated second lowest on hedonic quality ($M = 4.57$), even though it scored the highest on pragmatic quality. This suggests that participants find some shapes impractical but nice, and vice versa. Corner Bend was perceived as having the lowest hedonic quality of all shapes ($M = 4.14$) and was rated significantly lower than all other shapes, except Area.

Shape also affected goodness ($\eta^2 = .042$), with Tapering being most highly rated ($M = 4.75$) and significantly higher so than Corner Bend and Area. Perceived beauty is also affected by shape ($\eta^2 = .064$). Here, Curvature is rated significantly higher than all other shapes (except Tapering). Tapering is rated significantly higher than Amplitude and Corner Bend.

The largest observed effect in this use scenario was the effect that shape had on perceived urgency ($\eta^2 = .330$) and on the willingness to attend to a notification ($\eta^2 = .225$). Corner Bend was experienced as the least significant notification shape ($M = 2.89$). This is 27% lower than the ratings of shapes with the highest urgency (Amplitude, Area, Zero Crossing). Tapering was significantly lower on urgency ($M = 3.29$) than all other shapes except Corner Bend. Consistent with the urgency scale, participants were more likely to react to notifications with Amplitude, Area, Curvature, and Zero Crossing (ranging from 82% - 88%) compared to Tapering ($M = 68\%$) and Corner Bend ($M = 56\%$).

*Effects of Levels of Change*
A MANOVA found significant differences among the levels of shape change (Wilks' lambda = .481, $F_{24,1480} = $

|  |  | N | Pragmatic | Hedonic | Goodness | Beauty | Urgency | Attend to? |
|---|---|---|---|---|---|---|---|---|
| Shape | Amplitude | 564 | 4.56 (.11) | 4.69 (.13) | 4.37 (.15) | 3.99 (.15) | 3.95 (.07) | 86% (3%) |
|  | Area | 564 | 4.65 (.11) | 4.62 (.13) | 4.22 (.15) | 4.26 (.14) | 3.98 (.08) | 85% (3%) |
|  | Corner bend | 564 | 4.48 (.11) | 4.14 (.14) | 4.29 (.14) | 4.06 (.14) | 2.89 (.10) | 56% (4%) |
|  | Curvature | 564 | 4.65 (.10) | 5.04 (.12) | 4.72 (.14) | 4.72 (.14) | 3.71 (.08) | 82% (3%) |
|  | Tapering | 564 | 4.85 (.12) | 4.57 (.15) | 4.75 (.16) | 4.51 (.15) | 3.29 (.11) | 68% (5%) |
|  | Zero crossing | 564 | 3.96 (.11) | 5.17 (.12) | 4.54 (.16) | 4.29 (.16) | 3.98 (.08) | 88% (3%) |
| Level | Low | 940 | 4.65 (.08) | 4.79 (.10) | 4.67 (.11) | 4.49 (.11) | 3.59 (.07) | 79% (3%) |
|  | Medium | 940 | 4.53 (.09) | 4.71 (.10) | 4.44 (.11) | 4.29 (.11) | 3.61 (.07) | 77% (3%) |
|  | High | 940 | 4.20 (.09) | 4.69 (.11) | 4.17 (.13) | 4.01 (.13) | 3.90 (.07) | 82% (3%) |
|  | Toward | 188 | 5.05 (.17) | 4.83 (.21) | 5.08 (.21) | 4.85 (.20) | 3.41 (.16) | 76% (6%) |
|  | Away from | 188 | 4.64 (.17) | 4.31 (.21) | 4.43 (.23) | 4.17 (.22) | 3.16 (.15) | 61% (7%) |
| Speed | Slow | 1598 | 4.52 (.07) | 4.64 (.08) | 4.49 (.09) | 4.33 (.09) | 3.64 (.07) | 78% (2%) |
|  | Fast | 1598 | 4.50 (.06) | 4.68 (.08) | 4.44 (.09) | 4.25 (.09) | 3.66 (.05) | 79% (2%) |

**Table 1. Experience and urgency of shape change in the *notification* use scenario based on ratings of 3196 video clips. Parentheses give 95% confidence intervals.**

$14.911, p < .001$), again with no interaction effects. Table 1 shows the differences across levels.

Because levels are related to the shape parameter, we first analyze the levels of low-medium-high. Justified by the MANOVA above, individual ANOVAs found significant differences among these three levels across all scales ($F$s between 7.72 and 24.10, all $p$s below .001) except hedonic quality ($F_{2,186} = 2.98, p > .14$). The three levels significantly affects pragmatic quality ($\eta^2 = .328$), goodness ($\eta^2 = .188$), and beauty ($\eta^2 = .183$). For these three scales, pairwise comparisons between low, medium, and high show that measures of experience go significantly down as the size of shape change increases. This is clear for pragmatic quality, goodness, and beauty, which fall 10% -11% as the size of shape change increases from low to high. Hedonic quality also falls as level of shape change increases, but not significantly so: the difference between low and high is only a 2% fall in hedonic quality). Thus, from an experience point of view, smaller shape changes seem preferable to larger ones.

The three levels of shape change affected perceived urgency ($\eta^2 = .259$). The sense of urgency goes up as the size of shape change increases from low to high. From low shape change levels to high levels, urgency increases by 9%. As discussed above, this is the opposite effect of what was observed with the experience measures. Level also affects participants' willingness to attend to a notification, but only as a small effect ($\eta^2 = .033$).

Next, we turn to the levels of Tapering: moving away from or toward the user. Individual ANOVAs show significant differences among these two levels across all scales ($F$s between 7.95 and 43.57, all $p$s below .001). This difference had a large effect on all measures of experience (PQ: $\eta^2 = .135$; HQ: $\eta^2 = .199$; Goodness: $\eta^2 = .166$; Beauty: $\eta^2 = .229$). In all cases, if the smartphone moves towards the user, all ratings increase significantly, ranging from a 16% increase in beauty to a 9% increase in pragmatic quality.

Moving away from or towards the user also affected urgency ($\eta^2 = .079$) and whether participants would attend to the notification ($\eta^2 = .144$). Moving towards the users gives an increase in 8% rating of urgency, compared to moving away from the user. Thus, the relation of movement to the viewpoint of the user seems to affect the experience strongly.

*Effects of Speed*
A MANOVA did not find a significant difference in the six scales based on speed of shape change (Wilks' lambda = .876, $F_{6,88} = 2.069, p > .06$). As Table 1 shows, the pattern is that experience measures are slightly higher for slow speeds than for fast speeds, but that these are small compared to the differences described above. Beauty, for instance, is 2% higher, whereas pragmatic quality is just 0.5% higher. For the urgency measures, the pattern is the opposite, but the differences here are also minuscule (urgency is rated 0.5% lower for slow videos than for fast ones).

**Hand Approach Use Scenario**
The purpose of the *hand approach* use scenario was to investigate the use of shape change to convey intentions or elicit emotions. A MANOVA found significant differences among shapes (Wilks' lambda = .713, $F_{15,1264} = 10.99, p < .001$). Individual ANOVAs showed that both the arousal, valence, and animacy differed significantly across shape ($F$s between 5.97 and 7.60, all $p$s below .001).

*Emotional Response*
Figure 5 shows participants' emotional responses to the shape changes plotted on the circumplex model of affect [33]. As the figure shows, all parameters of shape change are near the center of model. This indicate that no shape change sparked extreme emotional responses.

Changes in Area evoked the strongest emotional response in terms of both pleasure and arousal and is the only shape parameter that is plotted in the first quadrant of the model. A post-hoc pairwise comparison confirmed the significance of this emotional difference. Changes in Area seem to create a mild feeling of delight or happiness. All other parameters made participants feel more calm than aroused with Corner Bend being the shape change that caused the lowest level of arousal. Interestingly, none of the shape parameters evoked the feelings that are associated with unpleasant arousal and belong to the second quadrant of the model (e.g, frustration, annoyance, anger).
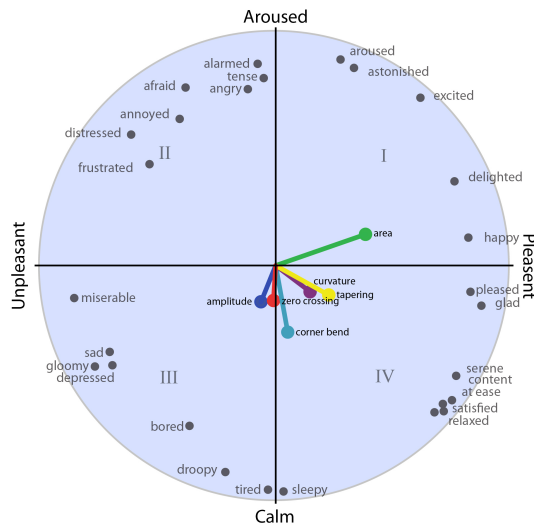
**Figure 5. Shape parameters plotted on the circumplex model of affect.**

| | Matter-of-fact | Intention | Emotion | Functional |
|---|---|---|---|---|
| Area | 89.9% | 1.1% | 0.4% | 8.7% |
| Curvature | 88.8% | 4.2% | 2.8% | 4.2% |
| Amplitude | 89.2% | 9.0% | 0.0% | 1.9% |
| Zero Crossing | 97.8% | 1.5% | 0.0% | 0.7% |
| Tapering | 88.7% | 9.2% | 0.0% | 2.2% |
| Corner Bend | 94.5% | 2.6% | 0.4% | 2.6% |
| Mean | 91.5% | 4.6% | 0.6% | 3.4% |

**Table 2. Distribution of the coding of the textual descriptions**

*Animacy*

Figure 6 shows the average level of animacy by shape parameter. Generally, all shape changes where perceived as having a high level of animacy with scores from around 7 and above. Corner Bend was the shape change that was associated with the lowest level animacy ($M$ = 6.93), and Area was associated with the highest level of animacy ($M$ = 7.63). Interestingly, Corner Bend and Area also scored lowest and highest in terms of arousal. This indicates a link between the levels of animacy and the resulting level of arousal.

We found no significant affect of the level of shape change on the level of animacy ($F_{2,184} = 1.64, p > .05$).

**Textual Answers**

For each of the videos in the *hand approach* use scenario, participants were asked to *"describe what you just saw"*. In this section we report on the results of the 1581 textual descriptions total (17 descriptions from 93 participants). The descriptions were coded by one of the authors using the following four categories: *Purely matter-of-fact*, *phone is expressing intention*, *phone is expressing emotions*, and *shape change serves functional purpose*. As Table 2 shows, the majority of textual descriptions were purely objective and matter-of-fact (91.5%). Amplitude and Tapering generated most descriptions of intention. In contrast, changes in Area generated the lowest number of description of intention, but the highest number of descriptions of functional purposes.
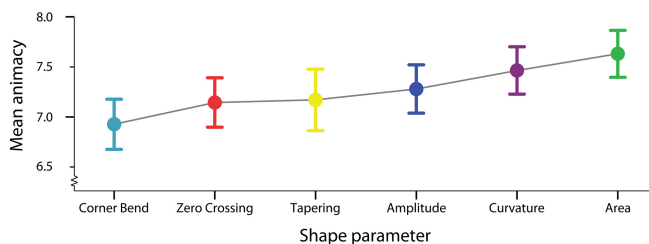


**Figure 6. Animacy by shape parameters.**

In the following we report the most important trends in the descriptions. In addition to investigating the intentional, emotional, and functional purposes of shape change, we look at what words participants used to describe the shape changes.

The words associated with changes in Area were *"increased in size"*, *"grew"*, or *"got bigger"*. Changes in Area was the shape change that most participants perceived as having a functional purpose: 8.7% of the descriptions interpreted the increase in area as a practical feature that allowed the device to function both as a smartphone and as a tablet. This feature seemed very desirable to participants. One participant was particularly enthusiastic: *"If a phone could grow that big and then go back I would pay crazy amounts of money for it"*.

When describing changes in Curvature, participants used the words *"curved up"*, *"arched up"*, or *"bridged"*. Many descriptions ascribe animal qualities to the shape change: *"like someone arching their back"*, *"like a cat"*, or *"like a caterpillar"*. Descriptions of intention is split between inviting (*"standing on two legs waiting to be picked up"*) to aggressive (*"seeming to bite at the hand"*). The descriptions of functional purposes envisioned that this shape change would allow the phone to be worn on the wrist (*"like a watch"* or *"like a bracelet"*).

Changes in Amplitude were described mainly with the words *"bulge"*, *"bump"*, *"hill"*, or *"mountain"*. However, a few answers (1.8%) indicate that changes in Amplitude might also have sexual connotations. Some participants described the shape change as *"an erection"*, *"kind of phallic"*, or *"an aroused nipple"*. Participants perceived Amplitude as an effort to *"meet the approaching hand"* or to get the users attention (*"I want attention and you need to deal with me NOW!"*). A few descriptions perceived the shape change as a way to help the user select the desired icon.

Zero Crossing was described very differently from participant to participant. The most common words were *"crinkled up"*, *"zig-zagged"*, *"rippling effect"*, *"jagged"*, and *"pleat"*. Zero Crossing mainly generated matter-of-fact descriptions. Only 2.2% of the answers described an intention of a functional purpose. The change in Zero Crossing was primarily perceived as a message to *"leave the phone alone"*.

Participants described Tapering by saying that it *"lifted up"*, *"raised up"*, *"expanded"*, or *"got thicker"*. Regardless of whether the phone tapered away from or towards the hand, the shape change was interpreted as an inviting gesture (*"lifts up like it is sitting in a chair and kind of says hello"*). One participant described Tapering as a *"build-in stand"*.

## DISCUSSION AND CONCLUSION

We have used videos of a shape-changing handheld device to collect measures of participants' experience, perception of urgency, animacy, and affect, and related them to parameters from models of shape change. Overall, the results show that manipulations of shape and the level of shape change had large effects on experience, perceived urgency, and emotions; the manipulation of speed had less effect. Next, we discuss these results in detail, outline some future work, and discuss limitations of the present paper.

### Shape Change Parameters

We have several remarks on shape change parameters. First, compared to other shapes, Corner Bend did not perform well, resulting in low scores on hedonic and pragmatic quality, arousal, and perceived urgency. Yet, Corner Bend is one of the most studied types of shape change for notification (e.g., in MorePhone [10]). We speculate that better alternatives for notification than Corner Bend exist. Our results suggest Area and Zero Crossing as interesting shape parameters for this purpose. Our results confirm earlier findings that Curvature is perceived as more urgent than Corner Bend [10].

Second, Zero Crossing worked well for displaying notifications and engendering a strong hedonic response. It was not – perhaps unsurprisingly – perceived as practical. This suggest, as many of our other results, that different shape changes may be useful for entirely different functions. For instance, Animated Mobiles [17] may not have chosen the best shape to reach its goal: Tapering did not score high on animacy compared to other shapes, although Hemmert et al. [17] observed that users attributed animacy to their prototype.

In addition to specific shapes, level of shape change had a surprisingly strong impact on experience and perceived urgency. Our measures of effect size suggest that it is larger than manipulation of shape. For instance, the direction of tapering changed participants' experience, so that movements toward participants were rated higher. Hemmert et al. [17] speculated that such movement would impact experience and provided qualitative data supporting this speculation. Our results seem to resonate well with this speculation. Further, it was interesting to see that smaller shape changes were perceived as giving nicer experiences (though less urgent) than larger shape changes.

Speed did not have much effect on participants' experience: differences are only a few percent on most measures. This was surprising because earlier work has speculated that speed is important to shape change (e.g., [32]) and because the differences in speed we used were quite large.

### Reactions to Video Clips

A key finding of this paper is that the effects of shape change are multi-dimensional. Zero Crossing was perceived as being nice but not practical; participants had strong reactions when describing changes in Area, but rated Area low on goodness. In some ways these effects are unsurprising, in other ways they highlight the need for richer, multi-facetted studies of user experience with shape-changing handheld devices (as argued by [31] for shape change in general). We believe that we have provided some rough, initial data on what shape changes may be used to which effect.

The textual descriptions from the *hand approach* use scenario showed that very few participants ascribed intentions or emotions to the shape changes when they were not explicitly asked to do so. Moreover, most descriptions of the shape change as a means to convey a message did not agree on the nature of the message. The convex curving of the phone was, for instance, perceived both as a gesture of greeting and one of defense. This suggests that it is difficult to convey unambiguous messages with shape change, given the limited shape vocabulary that current prototypes allow.

### Limitations and Future Work

Our study leaves several open questions. We varied only a limited set of shape changes and, with the exception of speed, we did not cross them. We have established first ranges of levels of shape change (low, medium, and high, in particular). Although these were derived from the literature, they are clearly a snapshot that needs to be refined and extended in future work. Also, the shapes we manipulated has several confounds: the most important of these is that the area that moves varies with what we call shape change. We also note that existing models do not clearly separate speed as a distinct parameter that must be crossed with other dimensions (e.g., [31]) and if they do, they say little about levels of speed (e.g., [32]). We hope to address these issues in future work.

We have argued that video clips are valid for studying experience. However, it is also clear that real interactions with products might work differently, for instance because of the ability to physically touch and manipulate the device. In some cases our results seem to confirm earlier work. For instance, our results show good agreement with MorePhone [10] in their investigation of urgency. We aim to validate our results with a real prototype that is capable of performing the shape changes used in this paper.

## REFERENCES

1. J. Alexander, J. Kildal, K. Hornbæk, V. Aaltonen, A. Lucero, and S. Subramanian. Interaction with deformable displays. In *Proc. of MobileHCI '12*, pages 237–240, New York, NY, USA, 2012. ACM.

2. J. Alexander, A. Lucero, and S. Subramanian. Tilt displays: designing display surfaces with multi-axis tilting and actuation. In *Proc. of MobileHCI '12*, pages 161–170, New York, NY, USA, 2012. ACM.

3. J. A. Bargas-Avila and K. Hornbæk. Old wine in new bottles or novel challenges: a critical analysis of empirical studies of user experience. In *Proc. of CHI '11*, pages 2689–2698. ACM, 2011.

4. C. Bartneck, D. Kulić, E. Croft, and S. Zoghbi. Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. *Int. Journal of Social Robotics*, 1(1):71–81, 2009.

5. M. M. Bradley and P. J. Lang. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry*, 25(1):49–59, 1994.

6. M. Coelho and P. Maes. Shutters: a permeable surface for environmental control and communication. In *Proc. of ITS '09*, pages 13–18, New York, NY, USA, 2009. ACM.

7. M. Coelho and J. Zigelbaum. Shape-changing interfaces. *Personal Ubiquitous Comput.*, 15(2):161–173, Feb. 2011.

8. J. Dawson, O. Schneider, J. Ferstay, D. Toker, J. Link, S. Haddad, and K. MacLean. It's alive! exploring the design space of a gesturing phone. In *Proc. of GI '13*, New York, NY, USA, 2013. ACM.

9. A. Girouard, R. Vertegaal, and I. Poupyrev. Special issue: Organic user interfaces. *Interacting with Computers*, 25(2):115–116, 2013.

10. A. Gomes, A. Nesbitt, and R. Vertegaal. Morephone: a study of actuated shape deformations for flexible thin-film smartphone notifications. In *Proc. of CHI '13*, pages 583–592, New York, NY, USA, 2013. ACM.

11. M. Hassenzahl. The interplay of beauty, goodness, and usability in interactive products. *Hum.-Comput. Interact.*, 19(4):319–349, Dec. 2008.

12. M. Hassenzahl, M. Burmester, and F. Koller. Attrakdiff: Ein fragebogen zur messung wahrgenommener hedonischer und pragmatischer qualität. In *Mensch & Computer 2003*, pages 187–196. Springer, 2003.

13. J. Heer and M. Bostock. Crowdsourcing graphical perception: using mechanical turk to assess visualization design. In *Proc. of CHI '10*, pages 203–212. ACM, 2010.

14. F. Heider and M.-A. Simmel. An experimental study of apparent behaviour. *American Journal of Psychology*, 57:243–259, 1944.

15. F. Hemmert, S. Hamann, M. Löwe, J. Zeipelt, and G. Joost. Shape-changing mobiles: tapering in two-dimensional deformational displays in mobile phones. In *Proc. of CHI EA '10*, pages 3075–3080, New York, NY, USA, 2010. ACM.

16. F. Hemmert, G. Joost, A. Knörig, and R. Wettach. Dynamic knobs: shape change as a means of interaction on a mobile phone. In *Proc. of CHI EA '08*, pages 2309–2314, New York, NY, USA, 2008. ACM.

17. F. Hemmert, M. Löwe, A. Wohlauf, and G. Joost. Animate mobiles: Proxemically reactive posture actuation as a means of relational interaction with mobile phones. In *Proc. of TEI '13*, New York, NY, USA, 2013. ACM.

18. M. Iacoboni, I. Molnar-Szakacs, V. Gallese, G. Buccino, J. C. Mazziotta, and G. Rizzolatti. Grasping the intentions of others with one's own mirror neuron system. *PLoS biology*, 3(3):e79, 2005.

19. H. Iwata, H. Yano, F. Nakaizumi, and R. Kawamura. Project feelex: adding haptic surface to graphics. In *Proc. of SIGGRAPH '01*, pages 469–476, New York, NY, USA, 2001. ACM.

20. W. Ju and L. Takayama. Approachability: How people interpret automatic door movement as gesture. *International Journal of Design*, 3(2):1–10, 2009.

21. J. Kildal, S. Paasovaara, and V. Aaltonen. Kinetic device: designing interactions with a deformable mobile interface. In *Proc. of CHI EA '12*, pages 1871–1876, New York, NY, USA, 2012. ACM.

22. H. Kim and W. Lee. Shade pixel. In *ACM SIGGRAPH 2008 posters*, SIGGRAPH '08, pages 34:1–34:1, New York, NY, USA, 2008. ACM.

23. S. Kim, H. Kim, B. Lee, T.-J. Nam, and W. Lee. Inflatable mouse: volume-adjustable mouse with air-pressure-sensitive input and haptic feedback. In *Proc. of CHI '08*, pages 211–224, New York, NY, USA, 2008. ACM.

24. S. Komarov, K. Reinecke, and K. Z. Gajos. Crowdsourcing performance evaluations of user interfaces. In *Proc. of CHI '13*, pages 207–216, New York, NY, USA, 2013. ACM.

25. B. Lahey, A. Girouard, W. Burleson, and R. Vertegaal. Paperphone: understanding the use of bend gestures in mobile devices with flexible electronic paper displays. In *Proc. of CHI '11*, pages 1303–1312, New York, NY, USA, 2011. ACM.

26. D. Leithinger and H. Ishii. Relief: a scalable actuated shape display. In *Proc. of TEI '10*, pages 221–222, New York, NY, USA, 2010. ACM.

27. Y.-k. Lim, S.-S. Lee, and K.-y. Lee. Interactivity attributes: a new way of thinking and describing interactivity. In *Proc. of CHI '09*, pages 105–108, New York, NY, USA, 2009. ACM.

28. W. E. Mackay, A. V. Ratzer, and P. Janecek. Video artifacts for design: bridging the gap between abstraction and detail. In *Proc. of DIS '00*, pages 72–82, New York, NY, USA, 2000. ACM.

29. C. Mancini, Y. Rogers, A. K. Bandara, T. Coe, L. Jedrzejczyk, A. N. Joinson, B. A. Price, K. Thomas, and B. Nuseibeh. Contravision: exploring users' reactions to futuristic technology. In *Proc. of CHI '10*, pages 153–162, New York, NY, USA, 2010. ACM.

30. A. Parkes and H. Ishii. Kinetic sketchup: motion prototyping in the tangible design process. In *Proc. of TEI '09*, pages 367–372, New York, NY, USA, 2009. ACM.

31. M. K. Rasmussen, E. W. Pedersen, M. G. Petersen, and K. Hornbæk. Shape-changing interfaces: a review of the design space and open research questions. In *Proc. of CHI '12*, pages 735–744, New York, NY, USA, 2012. ACM.

32. A. Roudaut, A. Karnik, M. Löchtefeld, and S. Subramanian. Morphees: toward high "shape resolution" in self-actuated flexible mobile devices. In *Proc. of CHI '13*, pages 593–602, New York, NY, USA, 2013. ACM.

33. J. A. Russell. A circumplex model of affect. *Journal of Personality and Social Psychology*, 39(6):1161–1178, Dec. 1980.

34. C. Schwesig, I. Poupyrev, and E. Mori. Gummi: a bendable computer. In *Proc. of CHI '04*, pages 263–270, New York, NY, USA, 2004. ACM.

35. J. Togler, F. Hemmert, and R. Wettach. Living interfaces: the thrifty faucet. In *Proc. of TEI '09*, pages 43–44, New York, NY, USA, 2009. ACM.