Exploring Haptics for Learning Bend Gestures for the Blind

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Abstract

This paper explores the use of haptic stimuli as non-visual affordances to assist in learnability of bend gestures. We tested 48 haptic Tactons with simulated blind participants to understand what haptic sensation could intuitively map to bend location and direction. We identify that a short, single motor Tacton indicates reliably a bend location, while participants agreed that the combination of two motors with varying intensities could indicate bend direction. This work is the first to explore the use of Tactons to communicate bend gesture location and direction, to eventually create a tactile interaction method for blind smartphone users

Author Keywords

Bend gestures; Deformable user interfaces; Visually Impaired; Accessibility; Haptics; Tactons; Usability.

ACM Classification Keywords

H.5.2. *User Interfaces–Haptic I/O, Interaction styles*

Introduction

Interacting with technology for the first time can be a challenge for any user. They need to understand new interaction paradigms, gestures and mental models, commit them to memory and successfully apply them to interact with a system. This challenge is even greater for a blind user who cannot rely on visual cues or on screen graphical elements to successfully navigate and interact with a system for the first time. Although technology exists to allow these users to interact with smartphones through touch based screen readers [1,11], the learning curve is high and often relies on inaccessible audio based tutorials or third party sighted users [8,28]. Usability issues for the blind also extend beyond this learnability phase and into general use. Relying solely on touch to interact with technology becomes increasingly challenging with nothing more than a flat glass screen to engage with. Although exploration into more tangible interaction methods spans a range of inputs [9,27], we are not aware of any research conducted in the area of learnability or usability of deformable interfaces with the blind.

By physically manipulating parts of a device, deformable User Interfaces (DUIs) and bend gestures offer a tangible interaction paradigm that could be well suited for the blind during all stages of a smartphone experience from learnability to general use [18,19,30,32]. Learning to navigate a list by bending easily locatable parts of a device such as edges and corners could greatly reduce user frustration and existing usability concerns. Taking this experience a step further, the combination of this bendable interaction paradigm with a tactile method of communication like haptic feedback could create a rich tangible experience for any novice blind user. Imagine in the early stages of using a device, receiving an audio cue to “bend here” as well as a specific locative vibration in the top left corner.

In this paper, we explore this novel tactile interaction paradigm and its potential mapping to certain types of Tactons (haptic vibrations used to communicate a message to the user). We explored a range of Tactons and parameter combinations, to in the future use for bend gesture learnability.

Related Work

We review previous work completed in the areas of accessibility and haptic feedback.

Accessibility

Researchers in the area of accessibility have identified usability concerns with touch-based screen readers. The constant need for complex multi finger interactions, accurate gestures and issues with text input, hierarchy of page content and navigation, lack of physical or tactile cues all pose challenges for the blind [7,21]. For instance, in a longitudinal study with the screen reader TalkBack with 5 blind users, Rodrigues et al. [28] identified that only one participant completed all stages of the tutorial. Some of the critical issues included: unable to perform simple gestures, distinguishing the edges of the screen, lack of tactile physical affordances and not understanding audio cues.

Haptic Feedback and Stimulus

Haptic stimulus for basic alert and notification vibrations can play a pivotal role in providing additional feedback to the user [23]. We specifically look at the use of Tactons [4] that, like their visual counterpart, help inform the user of the current state of the system using haptic feedback. Researchers have designed and used Tacton parameters such as Duration (length of Tacton), Amplitude (intensity of vibration), Rhythm (grouping together pulse vibrations with gaps), Melody/Wave Form (different amplitude and pulse vibration patterns), Roughness (combinations and

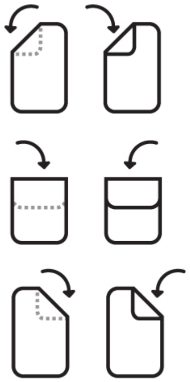

Figure 1. Six bend gestures used in study 1: Top left, top center and top right, down and up.

variations in amplitude), Spatial Location (different motor locations), and Motor Combination (use of one or more motors) [4,5,6,24,31]. Additional work explored meanings within Tacton design [15], such as short vibrations for error messages or circular patterns for progress indicators, and researchers have studied the use of haptic motors to enhance touch screens [7,25,29]. Tactons triggered at device corners have a higher accuracy of recognition than middle areas [29], and spatial and directional Tactons has a 93% accuracy of identification among users [33]. We use these parameters to shape our study.

Study: Tactons and Learnability of Bends

The learnability of invisible interactions such as bend often become challenging for blind users who are unable to watch instructional videos, or onscreen visual affordances to help guide them. We propose the design of a more tactile approach that could assist in bend gesture affordances when visual prompts are not accessible. Existing research demonstrates the effectiveness of haptic stimulus to prompt touch interactions [33], yet we are unaware of existing research exploring their application with bends.

Our goal with this study is to evaluate if consensus exists among users for selection of location and z-axis bend direction based on a combination of defined Tacton parameters. Based on prior work, we hypothesize that the location parameter of a Tacton can effectively tell the user which location to bend, e.g. that a Tacton emanating from the top left corner will prompt the user to bend the top left corner. We hypothesize that the intensity, waveform, motor combination and duration parameters can be used to identify which direction to bend (up or down). Our objectives are to identify which Tacton parameters can more effectively prompt the user to accurately select a bend gesture location, and identify agreement among participants for bend direction based on different Tacton parameters.

Bend Gestures: We focused on six basic navigation bend gestures proven to be successful location and interaction choices [10,14,32] (Figure 1). We selected bends performed on a smartphone in portrait mode, based on prior work [10,20], as well as on the adoption of this orientation within the general population [13].

Tacton Design: The literature indicates that we can use the location of the Tacton to prompt bend location [2,5,15,29,33]. However, since we are unaware of prior work that use haptic stimulus to prompt gestures in the z-axis, bend or otherwise, we investigated a variety of parameters that could prompt this (up or down, in the z-axis): intensity, waveform, motor combination and duration. Table 1 describes the Tacton parameter variables, illustrated in Figure 2. The intensity parameter for the bend prompt can indicate a mapping of increase or decrease in vibration to a bend direction

Intensity	• Low (~0.65g) to High (~1.4g) • High (~1.4g) to Low (~0.65g)
Waveform	• Sine wave • Square wave
Motor Combination	• Single - one of the 3 top locations • Dual - one of the 3 top locations and the bottom location
Duration	• Short (~0.450s)Long (~1.050s)
Location	• Top left • Top center • Top right

Table 1. Parameter variables: motor combination, duration, waveform, intensity and location.

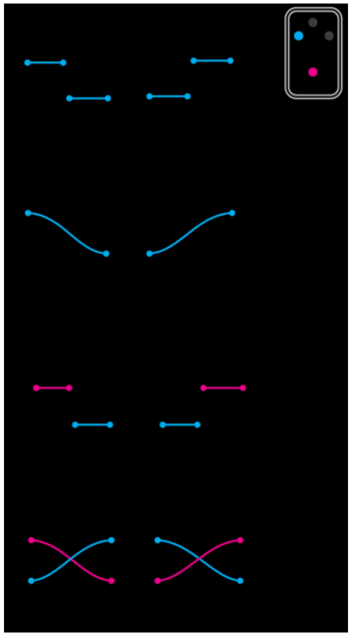

Figure 2. Simplified charts visualizing Tactons of a long duration for a single location (Top Left).

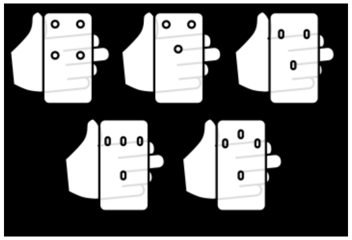

Figure 3. Evolution of motor combinations, placement and orientation. We used prototype 5 in our study.

of up or down. We also explored the use of one and two motor combinations with respect to a bend prompt. Two motor combinations used one of the top location motors (left, center, right) and a central bottom motor. This simulated a directional pattern from top to bottom, or bottom to top on the prototype, similar to that of Yatani and Truong when mapping touch gestures [33]. We incorporated two previously distinguishable wave types, Square and Sine [15], along with recommend Tacton duration of 0.1 and 2 seconds [15] to understand if changes in waveform or duration would affect the participant's mapping or reaction time. The four parameters, with variations in location, produced 48 Tactons (3 locations x 2 durations x 2 intensities x 2 waveforms x 2 motor combinations).

Haptic Prototype

We designed a prototype that used 4 pancake vibration motors to deliver the 48 Tactons. It approximates the size of an iPhone 4S (120 mm x 72 mm). Our prototype uses a stiff cardboard that could be bent into a concave shape to form a closer bond to the hand, a requirement to achieve maximum effectiveness of a vibration [33].

We iteratively explored configurations using 3 and 4 motors (Figure 3). The 3 motor options (prototypes 2-3) used both top motors to indicate a top center down, which was confusing to pilot participants, mainly causing of misidentification of top center and top right locations. We added a fourth motor (prototype 4) and misaligned them to prevent this problem (prototype 5). In addition to the motor placement, the orientation of the motors created variations in the vibration spread. Earlier prototypes (1 and 2) affixed the motors flat against the backing, resulting in a more distributed vibration through the rest of the phone and a higher rate of misidentification at other locations. Once we turned the motors vertically, the wave disseminated in the z-axis, for a more localized stimulus. This approach differs from previous work [4,16,33], and iPhone 5 or Samsung Galaxy S4 phones, like our first prototypes.

Methodology and Design

We designed a 3x2x2x2x2 repeated measures within-subject design, with the independent variables: Tacton location (top left, top center, top right), intensity (increasing, decreasing), duration (short, long), waveform (square, sine) and motor combination (one, two). Dependent variables include: Bend direction (up, down) and location (top left, top center, top right). Each Tacton repeated up to 4 times with a 2-second pause between each repetition to allow users time to identify the Tacton.

Participants first completed a set of demographic and expertise questions. The researcher demonstrated the 6 bend gestures on a silicone phone cast, and participants could practice until they became comfortable with them. In a training phase, participants were presented with location-based vibrations to ensure they could correctly sense vibrations through the prototype. We used a single top motor with constant intensity or waveform. Once they achieved 5 correct answers out of 6, they started the testing.

The system presented Tacton randomly to users who had to map it to a bend location and direction. Participants did not physically input their choice on a bendable phone, instead they used an onscreen UI to input the location and direction (Figure 4). During the testing, participants positioned the haptic prototype out of sight, to simulate visual impairment. This technique

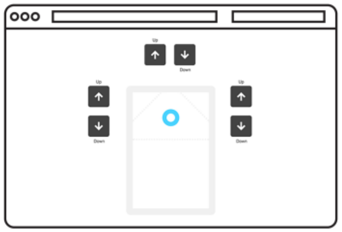

Figure 4. Screenshot of the user interface for inputting the choice of bend once presented with a Tacton. 6 Options included: top left up and down, top center up and down, top right up and down.

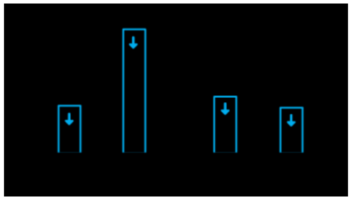

Figure 5. Participant's bend selection based on motor combination and intensity.

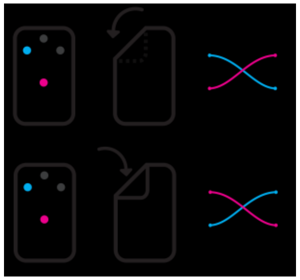

Figure 6. Mapping of participants Tacton perception to bend direction agreement.

was used in 3 previous studies to evaluate interaction techniques for keypads [22], Tacton usage as non-visual cues [26], and prompting of touch gestures [33].

17 normal sighted participants (12 male) were between 21 and 44 year old (mean of 31). The average technical proficiency was 5.1 (1 being poor to 7 being excellent). 10 participants had limited experience with bend gestures. They were compensated $10 for their time.

Results

We gathered location and bend choice, task reaction time and participants' confidence with their decision.

Bend Location: 75.41% of users identified the location correctly across all variables: 80.75% identified the top left location correctly, 74.81% the top center location correctly and 70.79% the top right location correctly. We aggregated bend choice results for each location and conducted a repeated measures analysis of variance test for accuracy rate against each parameter and location. We found statistical significance for the motor combination factor $(F(1, 9)=9.893, p=.012)$, and motor and duration combination $(F(1, 9)=15, p=.004)$. For the motor factor, single motor lead to a higher accuracy (82.54%) than double motors (67.82%). We ran a post-hoc, Bonferroni corrected estimated marginal means test for the interaction between motor and duration. We found a significant effect for the combination of single motor and short duration resulting in an 89.2% accuracy $(p=.045)$, and for the combination of the single motor and long duration resulted in a 79.2% accuracy $(p=.036)$.

Bend Direction: We again aggregated the bend choice among all three locations and conducted a Factorial Logistic Regression test between the direction of the gesture performed and the parameters. We found the pairing of an increasing intensity and two motor combinations to be significant $(p<.0005)$. Figure 5 illustrates the bend choice of participants when presented with this pairing of motor combination and intensity. With the double motor Tactons, 77.78% of participants selected bending down with an increase in intensity, while 65.78% of participants selected bending up with a decrease. Single motor Tactons do not result in a consensus on bend direction: the majority of participants selected both intensities as an up direction. Figure 6 illustrates the mapping of these double motor and intensity parameters to the vibration feel when holding the prototype. Double motor Tactons that fade from the bottom motor to the top are mapped to a bend up, where a fade from a top motor to the bottom is mapped to a bend down.

Mapping Confusion: Participants found one motor Tactons more confusing than two to prompt bends (Figure 7), though a Wilcoxon signed-rank test did not find significance between the two number of motors (p=0.06). During additional questioning, four participants identified "just guessing" at the single motor Tactons with respect to bend direction. Four participants identified the top center vibration as harder to distinguish than other locations and felt it more muffled and travelled to other parts of the device.

Discussion

Our study explored the indication of bend gestures through tactile means and identified that certain types of haptic stimulus could intuitively prompt a user to perform a certain bend gesture. We tested 48 Tactons varying in location, intensity, duration, wave and

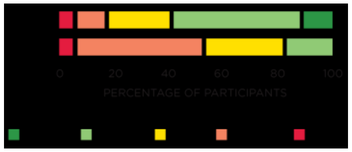

Figure 7. Likert Scale responses when asked to rate the confusion level for single and double motor Tactons.

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number of motors. We recorded participants' location and bend direction choice for each Tacton along with completion time. The corner closest to the thumb is a consistently reliable location for a haptic stimulus prompt: our location accuracy rate reached 80.75% at the top left location, an improvement of over 7% compared to past work at a 73% [29]. We found similar improvement in accuracy across locations. We believe that although slightly higher, our results are consistent with past work and re-enforces the accuracy of location with Tactons.

To identify the bend location, we found participants were most accurate with a single motor, particularly with short Tactons (89%). For bend direction, participants agreed that two motors were better, with a decreasing intensity indicating an up and an increasing intensity indicated a down gesture (78%). This is also supported by our confusion ratings, where 83% of participants indicated that using two motors did not confuse them when prompting bend direction. Overall, the gesture agreements found are lower than previous work using touch gestures [33]: we believe this result is due to the fact that bending in the z-axis is a more complex interaction to communicate using haptic stimulus than touch interaction.

The contrast between the accuracy of location with single motor Tactons and the agreement between participants around the use of two motors as an indicator to bend direction presents an interesting design challenge. Future work could explore the combination of a short single vibration in a corner to identify location followed by a two motor vibration to indicate direction. With almost a 92% accuracy rate for the corner closet to the thumb using a single motor Tacton, the user could effectively interact with the interface and reliably receive haptic feedback and stimulus from the system. We also see further expansion of work completed by Hoggan et al. [15] and the use of Tactons to convey specific types of notification meanings in combination with bend direction prompts. For example, a vibration traveling from the top right to the bottom could indicate not only that the user has an incoming phone call but also the bend gesture required to answer the call. These qualitative findings add value for bend gestures and the use of haptics as non-visual prompts.

We acknowledge a major limitation of our work in our choice of participants: we used sighted participants with simulated vision loss. While this is consistent with prior methodologies, it is not a correct representation of the target demographic. Blind users develop a heightened sense of touch and hearing to compensate for vision loss [3,12,17]. This might make them more sensitive to haptics, and react differently to our Tacton prompts. We will follow up with blind users to confirm our findings. Another limitation is the use of onscreen buttons to select bend gestures, which could have created a disconnect between the haptic stimulus received and bend action chosen. Participants might not have truly associated the Tactons with z-direction gestures but instead the on screen arrows. A follow up study with a bendable prototype that vibrates is necessary.

Overall, this paper is the first to explore the use of Tactons to communicate bend gesture location and direction. We discussed issues relating to the design of a flexible smartphone designed for the blind.

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