Effects of Bend Gesture Training on Learnability and Memorability in a Mobile Game

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ABSTRACT

Bend gestures can be used as a form of Around Device Interaction to address usability issues in touchscreen mobile devices. Yet, it is unclear whether bend gestures can be easily learned and memorized as control schema for games. To answer this, we built a novel deformable smartphone case that detects bend gestures at its corners and sides, and created PaperNinja, a mobile game that uses bends as input. We conducted a study comparing the effect of three pre-game training levels on learnability and memorability: no training, training of the bend gestures only, and training of both the bend gestures and their in-game action mapping. We found that including gesture-mapping positively impacted the initial learning (faster completion time and fewer gestures performed), but had a similar outcome as no training on memorability, while the gestures-without-mapping led to a negative outcome. Our findings suggest that players can learn bend gestures by discovery and training is not essential.

Author Keywords

Deformable user interface; Bend gestures; Learnability; Memorability; Mobile game; Around Device Interaction.

ACM Classification Keywords

H.5.2. User Interfaces - *Training, help, and documentation*

INTRODUCTION

Interaction with touch-based mobile devices suffers from issues such as occlusion and imprecision [26]. One solution is Around Device Interactions (ADI), which extend the interaction regions beyond the device [4]. By taking mid-air or near-device hand gestures as input, ADIs allow novel techniques that take advantage of the space around the display; thus create opportunities to improve user experience for a variety of applications, including mobile games [13]. While game designers have made creative use of devices' built-in sensors to augment the gameplay experience, for example, a labyrinth game where a player tilts the device to control the angle of a virtual maze, or a driving game where a player rotates the device to steer, ADI broadens this augmentation by allowing interactions that are not limited by the hardware of the mobile device, at the same time introduce better mappings between gestures and in-game actions.

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Figure 1. The player bends the flexible case to shoot paper airplanes to break the wall in the PaperNinja game.

We propose using deformation as an ADI for mobile games, and present a flexible case for a rigid smartphone to support bend gestures (Figure 1). We believe this ADI setup is particularly suitable for games, as it not only addresses the occlusion and imprecision issues, but also introduces unique metaphors between tangible bend interactions and matching in-game effects. To illustrate this, we created PaperNinja, a 2D platformer game that controls a piece of paper to pass through obstacles by bending various parts of the case.

While researchers have developed scenarios for deformable devices including turning e-book pages, scrolling up and down, zooming or scaling, map navigation, and gaming [1, 14, 29], it is unclear whether this new form of input will be easily learned and retained, and how the gestures are mapped to actions. This is particularly important for mobile games that emphasize on the "anytime, anywhere" aspect [16] where players can start playing quickly.

In this regard, we investigated three aspects of bend gestures: Can bend gestures be learned and performed efficiently without training? Are bend gestures and their mapping to actions memorable after a period of non-use? And, if used, how do different training strategies affect the learnability and memorability of bend gestures? We measured learnability and memorability of the gestures in a two-session user study, one week apart. Our study reveals that the mapping from gestures to actions is beneficial, but only in the short term.

RELATED WORK

We first describe related work on ADIs, flexible devices and gestures, we then review prior work on learnability and memorability within the HCI community.

Around Device Interactions (ADIs)

Researchers have proposed various methods to take gestures in the device's surroundings as input, mainly to address the aforementioned issues with touchscreens. SideSight [4] uses proximity sensors at the edges of a phone to detect touch gestures near its sides, HoverFlow [15] takes a similar approach but points the sensors upwards to detect hand gestures above the phone. Abracadabra [11] and Nenya [3] use a magnetometer to track a magnet's trajectory to detect mid-air gestures for a wrist-worn device. MagGetz [12] and MagiTact [13] apply this concept to mobile devices.

However, we found little work in using deformation as ADI, except SqueezeMe [21] that embeds pressure sensors in a tablet case and allows application manipulation by squeezing the edges of the tablet. To our knowledge, no previous work has used bend gestures, which are known to be superior in tangibility [1]. We built our prototype to fill this gap.

Bend Gestures and Games

Bend gestures are typically defined by the location(s) (e.g., corners, sides) and the direction (upwards or downwards) of the force that causes the bend [31], of which people tend to prefer the top corners and the top side the most [19, 20]. A few research projects have implemented bend gestures as input for games (e.g., Cobra [32], BendID [24], Softii [23], Bendy [19]). In particular, Bendy [19] recommends that bend gestures be mapped to navigation on a 2D plane, or to the deformation of an object in the game. They found that the closer the interaction mimicked a real-world deformation action, the easier it was for users to use the gesture. We used these results to help create our bend gesture mappings.

Learnability in HCI

Anderson and Bischof [2] separated gestures learnability into two factors: 1) the ability to perform a gesture; and 2) mapping between the gesture and the resulting action. We find this distinction especially important when it comes to gestures fully new to users, such as bend gestures. However, we found little consensus in defining and evaluating learnability within a user interface. Grossman et al. [10] surveyed methods to examine software learnability and revealed that various metrics for learnability do exist but are scattered across various research papers. As there was no single collection of learnability metrics, the authors listed a set of usability metrics, from which we drew inspiration in designing the metrics we used, including the assessment of task completion times in evaluating initial learnability [25].

On the other hand, the Guidance Hypothesis [27] suggests that excessive guidance (in the form of knowledge of results, such as augmented feedback) during training degrades motor learning by fostering increased dependence on the guidance.

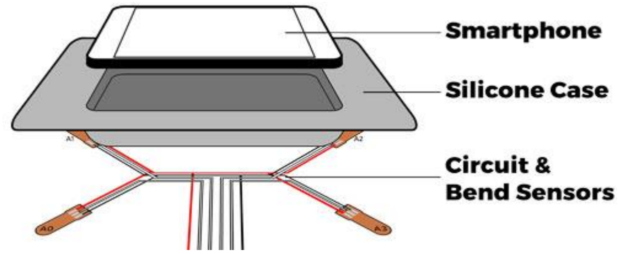

Figure 2. Exploded view of our flexible prototype (168 mm * 111 mm): flexible bezel (25 mm wide, 10 mm thick) with four bend sensors encasing an LG Optimus L5 ii smartphone.

Anderson and Bischof [2] validated this hypothesis in pen gesture learning by providing participants with different amounts of guidance: the more guidance provided during training, the worse the retention became. We hope to validate this theory in the context of flexible devices.

Memorability of Gestures

To test memorability, researchers suggested that tasks performed during the learning phase should be tested at least one night after [28]. Maqsood et al. [20] studied the memorability of passwords on a flexible smartphone by evaluating users one week after they created a bend-gesture password. Results showed that users could remember bend passwords as well as PINs, demonstrating that bend gestures can be recalled. Nacenta et al. [22] studied the memorability of user-defined touch gestures versus pre-designed gestures, and found users perceived user-defined gestures as easier to remember after one day, more fun, and required less effort.

THE FLEXIBLE PROTOTYPE

We designed a flexible case to augment a rigid phone with bend gestures as ADI. The prototype includes a smartphone with a 4" (101.6 mm) display encased in a flexible sleeve with bend sensors (Figure 2). We made the sleeve in silicone (Alumilite 60A), creating a flexible bezel that bends easily and, when at rest, quickly returns to its original shape. Ergonomics factors, such as devices size and affordance of grip, are important for the usability of deformable devices [18, 31]; we chose a bezel size which is easily held and bent, similar in size and thickness to many commercial tablets.

Our prototype detects bends on all four corners and sides using four 1" FlexPoint bend sensors [8], in both the upward and downward directions (measuring up to -/+90º). The bend sensors are connected to an Arduino Leonardo circuit board, which powers the sensors and relays their readings to the smartphone via a connected Bluetooth module.

LEARNABILITY AND MEMORABILITY EXPERIMENT

Our main research goal is to determine if individuals require training to learn how to perform bend gestures efficiently, with a secondary goal to evaluate bend gesture memorability. We designed a study consisting of two sessions, one week apart, with the first session evaluating gesture learnability, and the second gesture memorability. We compared three types of pre-game training:

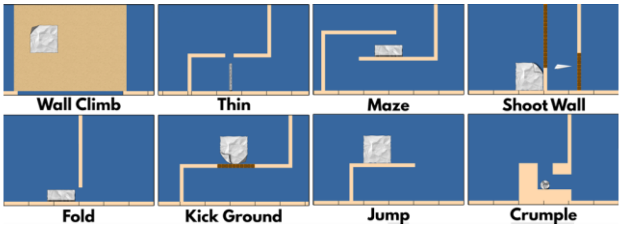

Figure 3. Eight obstacles presented in PaperNinja.

- **Mapping Training:** Users undergo a tutorial on how to perform gestures and their association to in-game actions.
- **Gesture Training:** Users undergo a tutorial on how to perform bend gestures, but without the mapping between bends and in-game actions.
- **No training:** Users begin the tasks with no tutorials.

We hypothesize that training will positively influence the learnability but negatively influence the memorability of bend gestures in a mobile game. Specifically, in the learning phase (first session), the mapping-trained group will perform best (H1), followed by the gesture-trained group (H2), both better than the non-training group. Based on the Guidance Hypothesis [27], we predict that the non-trained group will perform better than the trained groups in the memorability phase (second session) (H3).

Game and Training Applications

PaperNinja is a 2D platformer mobile game where the player maneuvers a piece of paper around obstacles to put the paper into a recycling bin. Figure 3 shows eight of ten obstacles, randomly ordered in every game. PaperNinja includes a first screen requiring the player to move to the right and a final screen, and drop the paper into the recycling bin to complete the level. We built the mobile game for

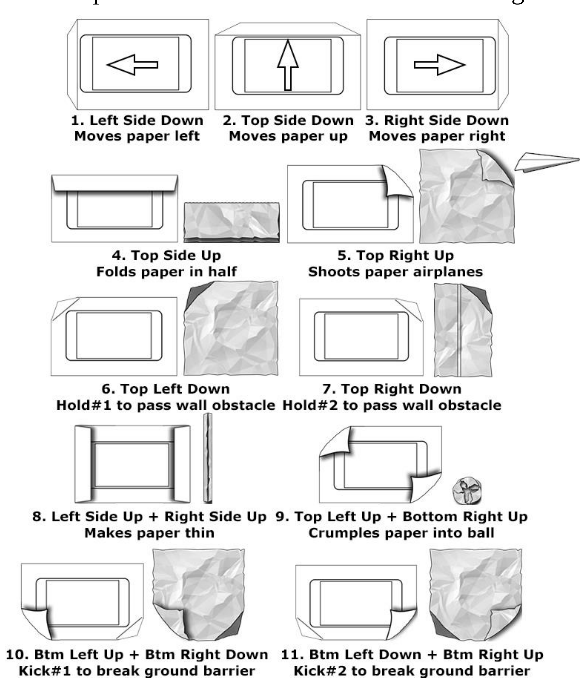

Figure 4. Bend gestures and their action mappings.

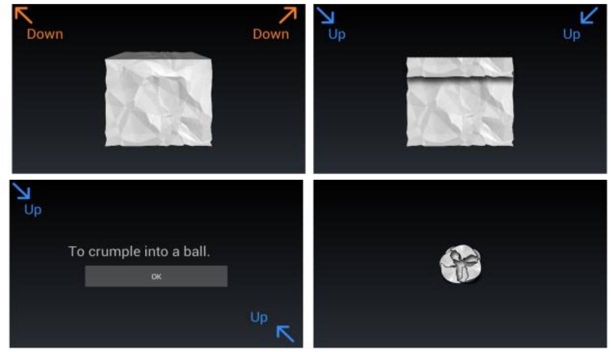

Figure 5. Screenshots for pre-game training: (top) Gesture tutorial showing a top edge bend, (bottom) Mapping tutorial showing an action description and its result.

Android using DroidScript (*http://droidscript.org/*) and Phaser (*https://phaser.io/*). We created a set of 11 bend gestures for the game (Figure 4), balancing ease of remembering and complexity based on prior work [9, 17, 30, 31]. We included bends in both directions, four corners, simple (single sensor) and complex (two sensors).

Gesture Training demonstrates the available bend gestures, and teaches participants how to perform them properly. The tutorial shows bend gestures through an animated piece of paper, with arrows in corresponding corners indicating the directions to bend (blue for upwards, orange for downwards, as per Daliri and Girouard [7], see Figure 5, top). The animation repeats until the player performs the correct bend. The tutorial does not show the resulting action, and places gestures in random order every time it runs.

Mapping Training provides additional training on top of the gesture tutorial by informing participants what in-game actions are mapped to the bend gestures. Each gesture begins with a screen describing the in-game action with directional arrows (Figure 5, bottom). Once the player taps the button, the animated piece of paper appears, showing how to execute the bend gesture, and repeats until it is performed correctly (same as the gesture tutorial). The tutorial then shows the resulting action of that bend gesture.

Methodology

We used a mixed design study consisting of two sessions set one week apart. The first session lasted approximately an hour and the second session half an hour. We equally distributed participants into three groups, each completing one training condition (between-subject factor): no-training (NT), gesture-training (GT), and mapping-training (MT). At the beginning of Session 1, the GT and MT groups went through their tutorial at least three times or until they felt comfortable. All three groups followed the same procedure in Session 2, where each participant played the game three times (within-subject factor). We collected the completion time and the number of gestures performed in each game, as per the learnability metrics proposed by Grossman et al. [10].

We asked our participants at the end of each session Likert-scale questions inquiring their perceived performance, and

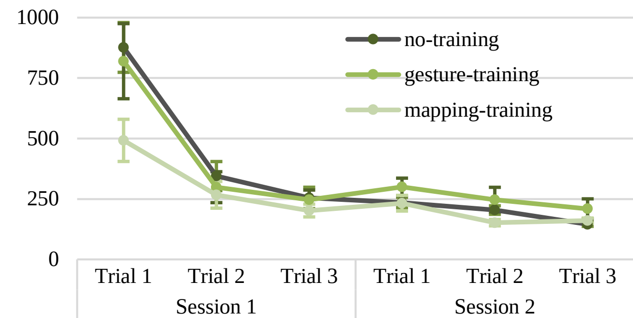

Figure 6. Completion time (seconds) of each training group. Error bars indicate standard deviation.

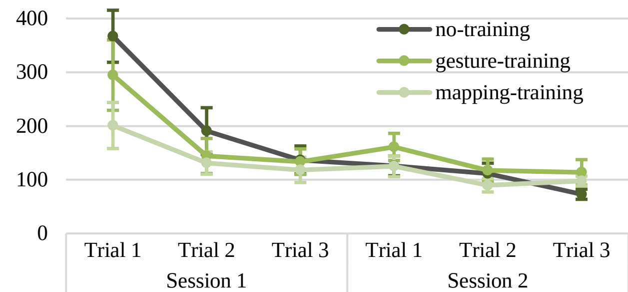

Figure 7. Number of gestures performed by each training group. Error bars indicate standard deviation.

ease and confidence in learning: Post-Session 1 questions included ease of learning, confidence in remembering and performing the bend gestures, how useful the tutorials were, and how well they thought they would have done with the tutorials (in conditions with tutorials). Post-Session 2 questions included ease of recalling the bend gestures, and self-evaluation of performing them.

Participants

Our 30 participants (11 female) had no prior experience with flexible devices or bend gestures. Their average age was 23 years old (SD=4.5). We compensated them with $10 cash after completing the second session. We received ethics clearance from the university research board for this study.

Results

The completion time per trial (game) is shown in Figure 6, while Figure 7 shows the number of gestures per trial. We associate higher time and number of gestures to lower performance. To test the effect of each training condition, we first ran a mixed factorial ANOVA using the sessions and trials as repeated measures within-subject factors, and the group's training levels as the independent variable for between-subject design. We report Cohen's d to indicate the effect size of significant comparison. We found all of them to be large (greater than 0.8 [6]).

Learnability – Session 1: We found a significant effect in Trial 1 for both time ($F(2, 27)=7.63$, $p < 0.01$) and number of gesture inputs ($F(2, 27)=6.14$, $p < 0.01$). A one-way ANOVA test with three Fisher's LSD post-hoc tests shows that the MT group was significantly faster than the GT group ($p < 0.01$, $d = 1.30$) and the NT group ($p < 0.01$, $d = 2.02$).

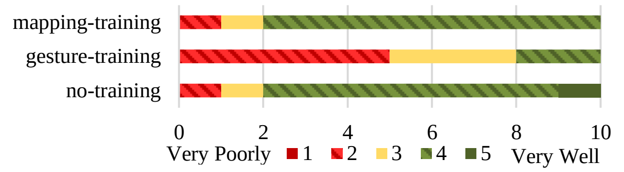

Figure 8. Participant perceived performance in Session 1.

When comparing the number of gestures performed in Trial 1, we found a significant difference between the MT group and the NT group ($p < 0.01$, $d = 1.82$). For Trials 2 and 3 of Session 1, we found no statistical significant differences between the groups in both timing and number of gestures.

Memorability – Session 2: We found a significant effect in Trial 1 for time ($F(2, 27)=3.79$, $p < 0.05$) but not for the number of gestures performed. For completion time, the GT group performed worse (took longer) than the MT group ($p < 0.05$, $d = 0.97$) and the NT group ($p < 0.05$, $d = 1.07$). In Trial 2, the GT group was slower than the MT group ($p < 0.01$). In Trial 3, the NT group had a faster completion time ($p < 0.01$, $d = 1.07$) and lower gesture count ($p < 0.01$, $d = 1.13$) than the GT group. In addition, the GT group also performed slower than the MT group ($p < 0.05$, $d = 0.81$).

To evaluate the effect of training on memorability, we compared the completion time in Trial 3 of Session 1 to Trial 1 of Session 2, since it was their first time attempting to recall the bend gestures. We only found a significant increase in the GT group's completion time ($F(1, 9)=23.66$, $p < 0.01$).

Post Experiment Questionnaire

Session 1: We ran a Wilcoxon test on the responses from the questionnaire and found only one statistically significant difference among the responses of the groups. Users from the GT group had significantly lower confidence in how they felt they performed compared to the MT group ($Z=-2.23$, $p < 0.05$) and the NT group ($Z=-2.41$, $p < 0.05$) (Figure 8).

Session 2: Another Wilcoxon test revealed no statistically significant difference among the responses in Session 2. Almost everyone found it easy to recall the gestures and mappings, and thought they performed well in the session.

Discussion

In general, our participants had a positive experience with the flexible prototype and the bend gestures. Many said that playing the game was intuitive and fun, that the bend gestures made sense, and the more they understood how they worked the more intuitive and natural the gestures became.

Effects of Training on Learnability

We observed an initial positive effect on performance with pre-game training, as indicated by significant differences in Trial 1 of Session 1. The mapping training (MT) group's lowest completion time confirms that MT has the best impact on learnability (H1). This could be explained by the lowered number of gestures performed to complete the game due to fewer unsuccessful attempts. However, our results do not support that gesture training is more beneficial than no training (H2), as we found no significant effect on the number of gestures or completion time between the gesture-training (GT) and the no-training (NT) groups. This is consistent with Anderson and Bischof's [2] suggestions that learning should involve mapping between the gesture and its resulting action. Because we deprived the GT group of the mapping, they had to map the gestures to the actions to the game themselves, and resulted in a similar completion time as the NT group. Participant comments indicated that they spent time trying to remember what gestures they saw instead of attempting various bends to pass the obstacle.

Moreover, the perceived performance in Session 1 matches the completion time result, suggesting that MT provided participants with confidence in their abilities, while gesture training was similar to them as no training. In addition, all three groups eventually reached the same performance level by the end of the first session, suggesting in-game learning.

Effects of Training on Memorability

Overall, participants remembered the gestures well between sessions, with only the GT group having a significantly lower performance. This result only partially validated our third hypothesis (H3), as well as the Guidance Hypothesis, in that the NT group performed better than the GT group. We believe the absence of negative impact on the MT group is likely due to the appropriate mapping between bend gestures, given the metaphor of the folding paper in our game.

One the other hand, the positive impact of no training on memorability could be explained by the fact that as the NT group did not know any bend gestures, they had to discover the gestures themselves in Session 1, and problem-solved their way through the game, thus retained more of such information, as described by the Guidance Hypothesis. This is evidenced by comments stating that the obstacles taking the longest time to figure out how to pass became the most memorable and easiest to recall.

Overall Effects of Training

Our findings suggest that when mappings are included, training helps with both the initial learning and memorability of bend gestures, and instills confidence in performing them, while the absence of mappings leads to worse results in memorability. This is because in such cases (GT), the player has to memorize all the gestures and then use what they remembered to complete the game. In the other cases, the player either learns the gestures during gameplay, or learns the gestures and mapping ahead, thus is better equipped to see the context in which the gestures will be used.

Our questionnaire reveals that our participants associated learnability and memorability of bend gestures with how much time and effort they spent to learn the correct bend gesture, adding that complicated gestures would bring them to a quitting point as they ran out of bends to try and could only rely on training, or guidance, to move forward. Therefore, as bend gestures become more sophisticated (e.g., combination, or sequence of bends), proper guidance is necessary to ensure they remain easy to learn and retain.

Recommendations

We propose two recommendations for using bend in games:

Training may not be necessary. Though helped initially, training eventually became irrelevant and unnecessary. Our participants who spent time going through bend gesture training reached the same performance as those who did not receive training. Therefore, training may be omitted for interactions in games with simple tasks.

If training is provided, map gestures to actions. If training is provided, it should make the gesture-to-action mappings as clear as possible, as the absence of such mapping would negatively impact memorability. We also recommend showing gestures during gameplay (in-game training) and in smaller groups in its intended context. However, this is not an area that we studied in-depth.

Limitations

Our prototype was limited by the current technology, as the bend sensors occasionally needed to be replaced during the study, leading to a less-than-optimal user experience. Also, the specific grip of users influenced the size of the bends they performed, where large bends sometimes led to accidental false positives, and small bends did not activate the sensors, leading to variations in measurements. Potential solutions include optimizing the design of the sleeve for better circuit and bend sensor integration, adapting triggering thresholds of bend gestures in real-time, and incorporating rigid parts to prevent bend gestures from propagating to other sensors.

Lastly, our small sample size (10 in each group), while close to the local standards [5], may restrict our results' validity.

CONCLUSION

In this paper, we evaluated the effects of training on the learnability and memorability of bend gestures to support around device interaction under the context of gameplay. Our results show that inclusion of mapping in training has some initial learning benefits, but has no lasting effect on performance when compared to no training. Furthermore, provision of gesture training without such mapping (gesture-trained) leads to the worst actual and perceived performance.

We believe bend gestures have a promising future in gaming. Our study explored an innovative way of playing mobile games using bend gestures as a form of ADI, and received positive feedback from our participants: many found them fun, intuitive and easy to learn. We intend to extend our research by investigating the ideal range of bend angles based on people's levels of comfort and control, evaluating in-game training, and providing gesture-to-action mappings in small groups. We also plan to evaluate training in different applications and game genres, or existing mobile games that do not have any correlation to bend gestures.

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