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

by

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Abstract

Flexible displays are making their way into handheld devices. Users can benefit from ways of interacting with these devices using bend gestures to activate a command. However, these devices may have a higher learning curve due to their complex degree of interaction. We developed a new deformable device that detects bend gestures, and created Paper Ninja, a mobile game that is played using bends. We compared the effect of training on learnability and memorability through three conditions and attempted to validate the Guidance Hypothesis. Participants played the mobile game in two sessions and received one of the following: 1) training on how to perform bend gestures, 2) bend gesture training as well as what action mapped to the gesture, 3) no training. Our study revealed that mapping training produced a similar outcome as no training, while gesture training led to a negative outcome. Our findings suggest training is not essential for users to learn bend gesture interactions and learning by discovery is feasible.

Acknowledgements

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1 Introduction

1.1 Overview

Deformable interactive displays are emerging in the field of Human Computer Interaction (HCI) (Troiano, Pedersen, & Hornbæk, 2014). Deformable displays, also known as flexible displays, allow for new types of gestures that involve a more complex degree of interaction compared to a rigid touch screen (Ahmaniemi, Kildal, & Haveri, 2014; Steimle, Jordt, & Maes, 2013). A flexible display can be defined as an elastic material whose shape can be changed by applying a force to it, while a bend gesture is the physical deformation of a flexible device to form a curvature that triggers an action on a display (Lahey, Girouard, Burleson, & Vertegaal, 2011). Flexible devices can solve user problems such as occlusion issues of touch screens (Ahmaniemi et al., 2014) and are found to be the preferred form of input for applications such as turning pages of an e-book reader, scrolling up and down, zooming or scaling, map navigation and gaming (Ahmaniemi et al., 2014; Kildal, Lucero, & Boberg, 2013; Shorey & Girouard, 2016).

However, since deformable devices are novel, it is not clear whether this new form of input would be easily learned and retained by users. Learnability is an important criterion to any novel interaction techniques (Anderson & Bischof, 2013; Haramundanis, 2001). For deformable devices to be practical, users should be able to demonstrate the ability to perform a bend gesture correctly. A second equally important aspect is memorability. Gestures need to be memorable for the user so they do not need to re-learn the same actions every time they use their device. Developing learnable material requires the information to be logical, re-constructible and consistent for the user (Haramundanis, 2001).

This thesis aims to examine bend gesture in three aspects, to determine:

1. If users can learn bend gestures and perform them efficiently without training.
2. If users can memorize a set of bend gestures and their mapping after a period of time.
3. How different training conditions affect the learnability and memorability of bend gestures.

Flexible devices have shown a high potential for usage in gaming since they provide an innovative input method for playing games (Ahmaniemi et al., 2014; Schwesig, Poupyrev, & Mori, 2004). Mobile games are a popular genre of applications because they are designed to be short, simple and engaging (The Nielsen Company, 2011). Since games appeal to almost every demographic (Casual Game Association, 2007), we decided to focus our examination of bend gestures by evaluating them in the context of a mobile game.

We created a new game called Paper Ninja that is played using bend gesture inputs. Paper Ninja is a 2D platformer mobile game where the user plays as a piece of paper. Moreover, we designed and built a new flexible prototype by augmenting a rigid smartphone with a deformable case as shown in Figure 1.

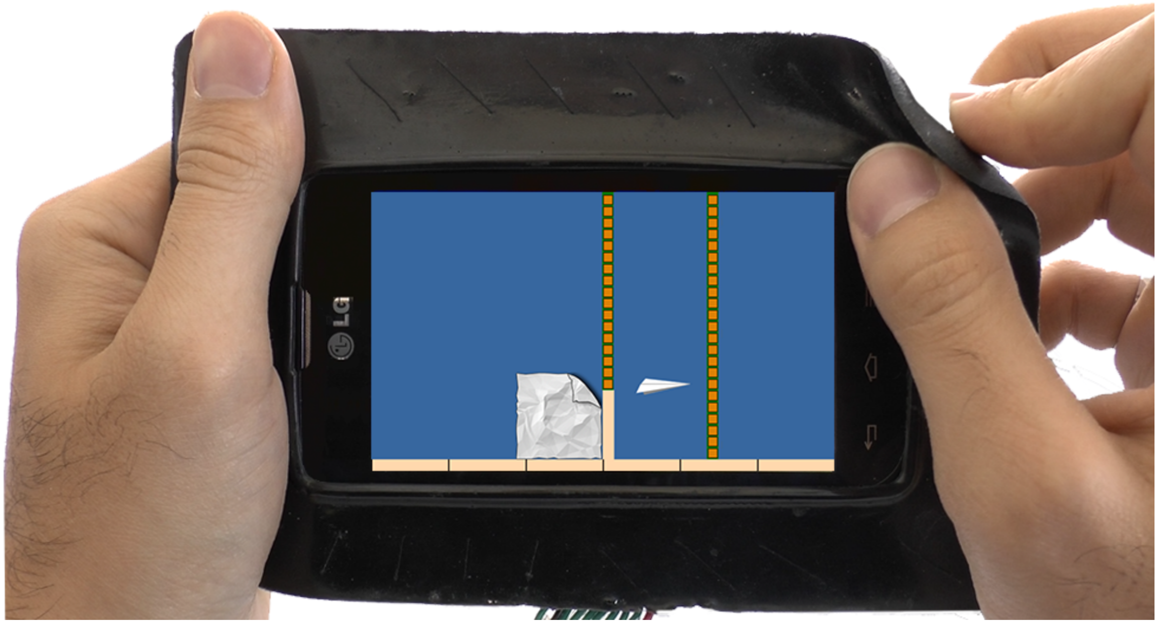

Figure 1: Example of bending the flexible prototype to enable an action in the Paper Ninja game. Image shows how to shoot paper airplanes to break the wall obstacle.

We then conducted a user study that consisted of two sessions, separated by one week.

Users were put in one of three conditions;

1. **The first group received gesture training**

   This means users were only trained on how to perform bend gestures but were not informed of what action the bends were associated to.

2. **The second group received mapping training**

   This means users were trained on how to perform the gestures and what action the gestures were associated to.

3. **The third group received no training**

   Users in this group began the tasks with no prior training.

All groups played the same mobile game using the same bend gesture inputs. To measure the learnability and memorability of each group, their game completion time and number of gestures performed were measured.

1.2 Contributions

We have two major contributions to flexible device research; firstly, the creation of a new flexible prototype and secondly, a study regarding the effect of training on learnability and memorability of bend gestures.

Our prototype encased a rigid smartphone and allows for deformable interaction with it. The prototype went through an iterative design process where we tested different types of material and different sizes to achieve a comfortable deformable product. Our flexible prototype leveraged the rigid screen to act as an anchor point to help users perform bends. Composed of a rigid small smartphone and a flexible case, our prototype was close to the size of an e-book reader, with the top of the flexible bezel arrived at the same level as the screen, and fit comfortably in the user’s hands.

We designed and ran a study to evaluate the effect of two types of training on learnability and memorability of bend gestures and compared them to non-trained users. Our experiment revealed new insights on the effects of bend gesture training which, to our knowledge, has not been addressed in previous research. Users showed a positive response to using flexible devices as an input for gaming which validates prior research findings. The study examined three different training conditions and their impact on recall times in both short-term and long-term memory. Using the results, we present recommendations for bend gesture training and game designers.

1.3 Thesis Outline

This thesis is composed of five sections. The first section presents an overview of our study and the motivations for investigating the learnability and memorability of flexible devices. The following section discusses related work on flexible devices, learnability in the HCI community, memorability and the Guidance Hypothesis.

The third section presents the development of our flexible prototype, the software used to build our mobile game and an apparatus of our setup. This section provides details of the prototype design, its hardware components and the software used to build the mobile game, Paper Ninja, and detect bend gesture inputs.

The fourth section provides details about our experiment and the tasks participants had to complete. This section includes descriptions of the tasks, participants, methods, results and discussion. In addition, we assess certain issues that occurred during our first attempt at running the experiment and why we had to repeat it.

The fifth and final section summarizes our findings and provides recommendations for flexible devices and game designers. We also discuss the limitations of our research and provide suggestions for future works.

2 Related Work

Research in deformable displays has increased greatly with the advancement of technology. We reviewed related work in flexible prototypes, deformable interfaces and gesture studies. Furthermore, we grounded our study in prior work done on learnability by looking at learnability within the HCI community and input modalities in mobile games.

2.1 Flexible Devices

Flexible devices allow users to give input by folding, bending twisting and squeezing the display (Kildal et al., 2013; Troiano et al., 2014). We surveyed prior work that explored different materials and sizes of flexible prototypes as well as research done on deformable interactions and summarized their findings.

2.1.1 Projected Display

Researchers have come up with different methods of building flexible prototypes. A common method is using projection onto a flexible surface embedded with sensors to detect bends. Daliri and Girouard (2016) used a Pico projector to display the interface on a flexible surface. Other similar setups are FlexPad (Steimle et al., 2013) which used a ceiling mounted depth sensing camera and projector and Cobra (Ye & Khalid, 2010) which used a shoulder mounted pico-projector. However, the drawback of this method is that it requires effort to maintain the display on the prototype and caused distortion during bends.

2.1.2 Combination of Flexible and Rigid Parts

Researchers also used prototypes containing both flexible and rigid parts. We find, in this category, prototypes that use functioning flexible displays. The Nokia Kinetic Device (Kildal, Paasovaara, & Aaltonen, 2012) was composed of a flexible OLED display with two rigid parts attached to the sides of the screen. The rigid parts use a strain gauge to detect deformation and triggered actions in applications such as image viewer and navigating a music player. Similarly, ReFlex (Strohmeier et al. 2016) used a flexible screen and rigid bezels on the sides of the screen for the user to hold and perform bends on. PaperPhone (Lahey et al., 2011) is a device that used a functioning flexible display. PaperPhone comprised of a 3.7” electrophoretic display with an array of thin film bend sensors on the back of the display. However, these designs possess a limitation to the number of bend gestures that can be performed. Only side bends could be made; both sides up, both sides down and twisting resulting in a small number of possible bend gestures.

Rather than having a flexible center piece with rigid edges, some researchers used a rigid display embedded onto a deformable surface. Gummi (Schwesig et al., 2004) attached a handheld sized TFT colour display to the center of a flexible base augmented with bend sensors as seen in Figure 2. Their prototype design showed that a deformable handheld device could be used effectively and enjoyably to perform a wide range of simple interaction tasks. The development of such a device represented an interesting and feasible direction for further work with flexible devices. To add to this, Bendflip (Wightman, Ginn, & Vertegaal, 2011) was built and used to examine input techniques for flexible devices. They also used both rigid and flexible form factors to evaluate input methods for e-book readers. Their results revealed that bend input had comparable performance to button input for navigation on flexible devices, and fewer errors.

Figure 2: Gummi prototype (Schwesig et al., 2004)

In addition, Marti and Iacono (2016) developed a prototype where a rigid screen was manipulated using the edges for input. Their study allowed users to squeeze the bezel to zoom in and out of a camera application. Though their prototype did not incorporate bend gesture, it did introduce a new concept of coating a rigid material to allow for new interactivity. They compared users taking pictures using a squeeze-to-zoom method versus slide-to-zoom and found that squeeze-to-zoom was more stimulating, pleasant and inviting to users. This had a great influence in how we devised our prototype design.

2.1.3 Deformable Interactions

We wanted to know how size of a deformable device effects user behavior and preference so we looked at work done by Lee et al. (2012). To address this question, the researchers used deformable mockup displays of two different sizes and observed users' interactions with them. The large size was the size of an A4 sheet of paper and the small size was that of a smartphone. They found that the small-sized deformable device is preferred but more gesture agreements were made when using the larger size display. This is verified with work done on Bendy (Lo & Girouard, 2017) where participants found it easier to perform bend gestures using a small device as well. We also took these results into account to help us determine an optimal prototype design.

2.2 Learnability in HCI

We found little consensus as to how learnability should be defined and evaluated within a user interface. We looked into Grossman, Fitzmaurice and Attar's Survey of Software Learnability (2009) to get an insight on how to examine learnability. Their survey revealed that various metrics for learnability do exist but are scattered across various research papers. Furthermore, as there was no single collection of learnability metrics, the authors generated a set of usability metrics (Appendix D) that we used to determine what to measure for our research. Assessing the completion time of users was one form of evaluating initial learnability (Nielsen, 1994).

Anderson and Bischof (2013) break down the learnability of gestures into two factors; mapping between the gesture and the resulting action, and second, the ability to perform a gesture. This lead us to create two training applications where one teaches the user how to perform the bends (gesture-training) and the other teaches gesture-training as well as what action each gesture is mapped to (mapping-training).

2.3 Memorability

To test memorability, tasks performed during the learning phase should be done at least one night after and all participants should be under the same level of independent variable (R A Schmidt & Lee, 1999). We found research indicating that sleep further improves performance of recently acquired skill (Savion-Lemieux & Penhune, 2005; Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002). They found that after an 8-week delay, users began to show significant decrements in correct recalls. In our study, we incorporated a 1 week distraction period between the learning phase and retention phase.

Maqsood et al. (2015) studied the memorability of passwords on flexible display devices. She evaluated how well users can create a bend-gesture password and remember it one week after doing so. Their results showed that bend passwords are a promising authentication mechanism for flexible devices indicating that users can easily remember bend gestures. Nacenta et al. (2013) studied the memorability of user-defined gestures versus pre-designed gestures. They found that significant preference was given to user-defined gestures even though the time difference to learn both sets was negligible. In general, users experienced user-defined gestures as easier to remember, more fun and required less effort. However, they do state that different designers could have achieved more memorable gestures. Furthermore, users could have found the user-defined gestures easier to remember because they spent more time creating them.

2.4 Mobile Game Input

Most interactions with mobile devices are done through touch input using small displays (Lo & Girouard, 2017). These small displays restrict the use of on screen game controls and limit game interaction due to occlusion caused by finger position (Siek, Rogers, & Connelly, 2005). Flexible displays help with this screen-occlusion problem by allowing input to be done without the need for on screen game controls. Furthermore, researchers have found that users prefer other forms of input besides touch. Zaman et al. (2010) compared input preferences of a smartphone device to a Nintendo DS and found that users preferred the physical input method significantly more. Chehimi and Coulton (2008) found positive user response when using an accelerometer to play a 3D shooter game. Nonetheless, not many researchers have explored deformation as an input for gaming applications. Cobra (Ye & Khalid, 2010) was meant to be used in gaming but the prototype was not formally tested. BendID (V. P. Nguyen, Yoon, Verma, & Ramani, 2014) and Softii (V. Nguyen, Kumar, Yoon, Verma, & Ramani, 2015) are prototypes that use pressure sensors as inputs but were informally tested with 3D games. Our research focused on the examination of bend gestures in a mobile game.

A paper by Leflar and Girouard (2014) explored opportunities in the domain of mobile gaming with flexible devices, by focusing on deformable inputs to control navigation in 3D virtual environments. The researchers considered how individuals use flexible devices, and how people navigate in 3D space. They found that participants did not generally bother bending the bottom corners of the device. Their findings suggest to place high frequency actions on top corners and to use bottom gestures for unimportant actions. We used these results to help create our bend gesture mappings.

2.5 The Guidance Hypothesis

In the era of new technologies that introduce novel methods of interaction, training becomes vital. However, too much training can have a negative effect. The Guidance Hypothesis (Requin & Stelmach, 1990) suggests that excessive guidance in the training phase can hinder learning since the user may become dependent on the guidance. This means that with high training during the learning phase, there is little retained by the user and with low training, the user retains more. This was validated by the work of Anderson and Bischof (2013) who talk about The Guidance Hypothesis in their research and achieved similar results. They used four conditions where users received different amounts of guidance and came to the same conclusion; the more guidance given during training, the worse the retention became for the participants. Our goal was to achieve similar results in our findings and validate this theory in the context of flexible devices. We were not able to find research that examined the learnability of bend gestures using flexible devices; thus, we attempt to fill this void.

3 Prototype

We wanted our prototype to be small, comfortable and easy to use. Our aim was to create a device similar to a handheld smartphone while allowing users to easily perform bend gestures. Our prototype took inspiration from prior work (Marti & Iacono, 2016; Strohmeier et al., 2016) who's prototypes contained flexible and rigid parts. We used a smartphone as our display and leveraged the rigid screen as an anchor point where a force can be applied to perform a bend. Our design was a portable prototype that allows bends to occur on all 4 sides and corners and bend in both the upward and downward direction. In contrast to prior work (Ye & Khalid, 2010), we did not want to project a display on a flexible surface because that would force the user to hold the device in a specific location in 3D space which requires cognitive effort. We also wanted the user to experience the flexible prototype as though it was one single device in contrast to prior work (Schwesig et al., 2004; Wightman et al., 2011) that had the display protruding the flexible surface with the flexible bezel placed under the screen instead of being on the same level as the top of the screen. Since no projector was used, the user was free to hold the prototype as they please. Our prototype was 168mm x 111mm and used bi-directional FlexPoint bend sensors (Bend Sensor, 2016) as shown in Figure 3.

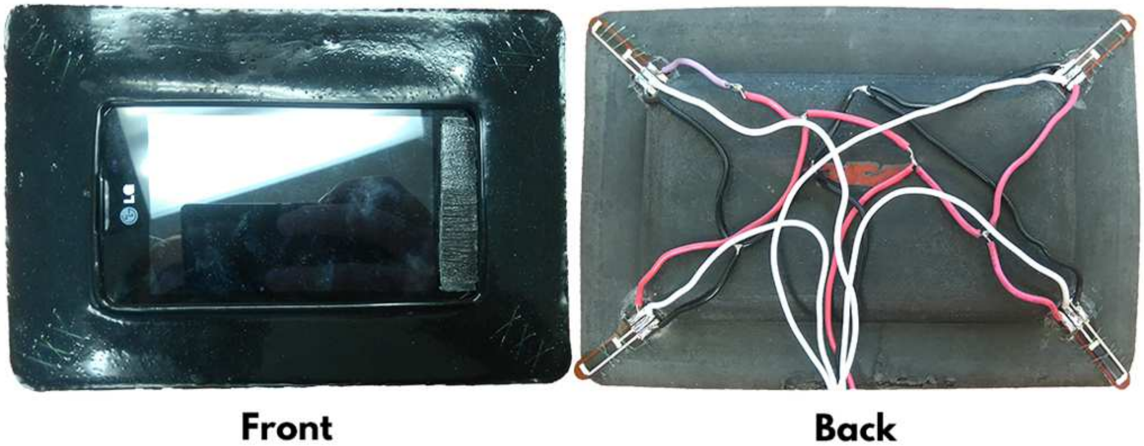

Figure 3: Final prototype - Flexible bezel (168mm x 111mm) encasing an LG Optimus smartphone with bend sensors and wires connecting to an Arduino Leonardo (not shown).

3.1 Hardware

To design this prototype, we encountered three main design challenges; First, we had to determine the appropriate bezel size, second, determine the appropriate bezel stiffness and thirdly, determine how the circuit wiring should be placed.

3.1.1 Device Size

We have seen that device size affects how users hold the device which in turn affects users' interaction and behavior (Lee et al., 2012). Large devices require more physical effort and repositioning of the hands leading to a negative experience (Warren, Lo, Vadgama, & Girouard, 2013). We initially decided to use a bezel size of 2 centimeters and performed bends on a mock prototype (Figure 4 Mold 1). We decided that the bezel needed to be wider and thinner because the smartphone prevented downward bends. Thus, we increased the bezel size to 2.5cm. We rounded the corners and added a larger curve to the back of the silicone (Figure 4 Mold 2) to make downward bends easier.

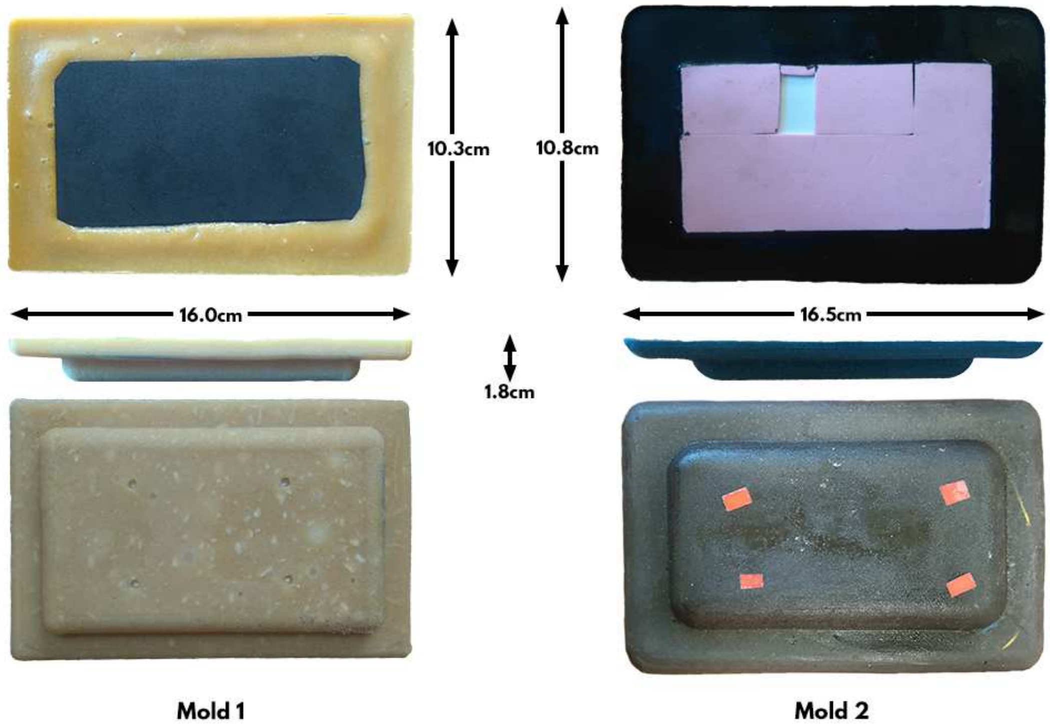

Figure 4: Differences between the first mold (Mold 1) and the second mold (Mold 2)

3.1.2 Device Stiffness

Given that stiff material requires too much force and users prefer bend gestures that are less physically demanding (Kildal, 2012), we selected material with low stiffness. However, we did not want to use material that had too little stiffness because that would prevent a bent edge from returning to its flat state on its own. We experimented with different stiffness levels and selected an optimal hardness. Silicone resin comes in different shore hardness ranging from 0 (lowest stiffness) to 100 (highest stiffness). We decided on using 60 to create our flexible bezel.

3.1.3 Device Wiring

We experimented with different types of wires and circuit designs. The iterative circuit designs are shown in Figure 5 and the process is described as follows:

1. **Version 1 – Eight Small sensors**

   After moderate usage, the data output of this layout was not stable. The wiring placement interfered with the bend sensors and data readings oscillated too much.

2. **Version 2 – Eight Medium sensors**

   The sensors were too long and protruded from the corners of the silicone bezel.

3. **Version 3 – Combination**

   We found this to be a prime combination of one small and one medium bend sensor in each corner creating a prototype with a total of 8 bend sensors. After conducting studies using this circuit design, we found that it created too many data errors and invalid measurements.

4. **Version 4 – Four small sensors**

   The experiment was repeated using the newly designed circuit. This provided the most flexibility and robustness which resulted in being the most successful prototype.

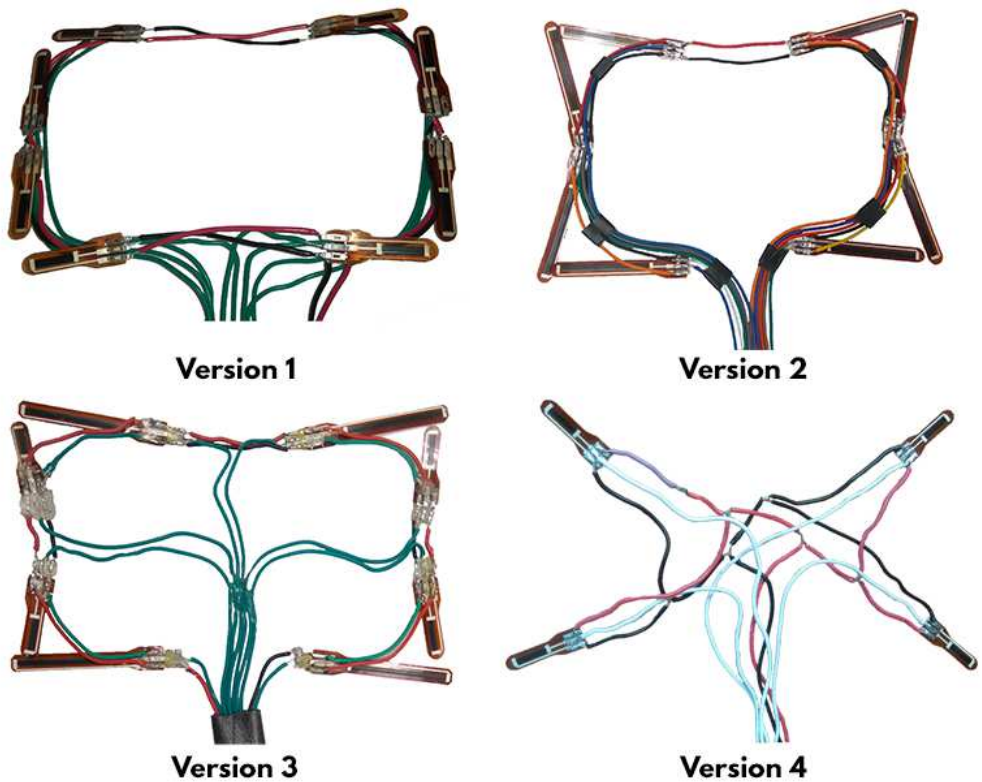

Figure 5: Iterative changes of the prototype's wiring and circuitry

Initially, we decided to place the flexible circuit inside the mold along with the phone case to become one unit after pouring the silicone as shown in Figure 6. We quickly realized this was not a practical prototype design. If one bend sensor was damaged, it left the entire prototype useless since the circuit was inaccessible. Therefore, the silicone was poured around the phone case first and then we attached the circuit to the back of the silicone using fishing wires to stitch the bend sensors in the corners and super glue to hold the wires in place (Figure 3 Back).

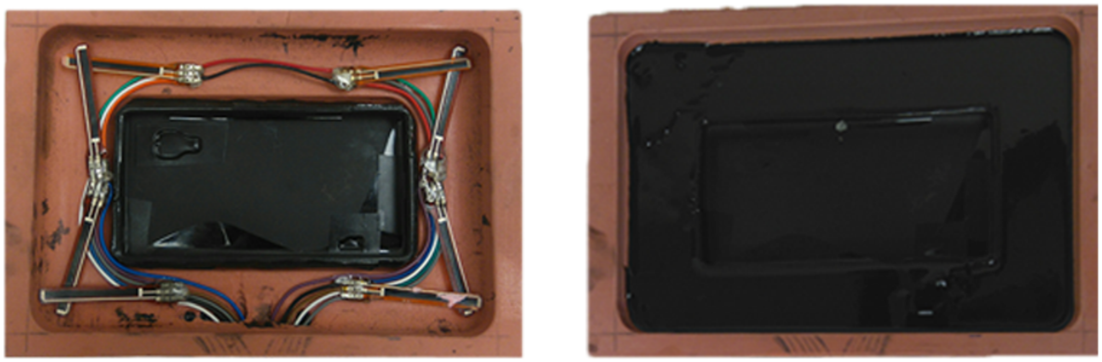

Figure 6: Making the flexible prototype with the circuitry before pouring the silicone solution and after.

3.1.4 Device Components

Our prototype is composed of 3 main parts: an LG Optimus L5 ii smartphone (LG Electronics, 2016) with a 4” display, encased in a flexible case augmented with bend sensors as shown in Figure 7.

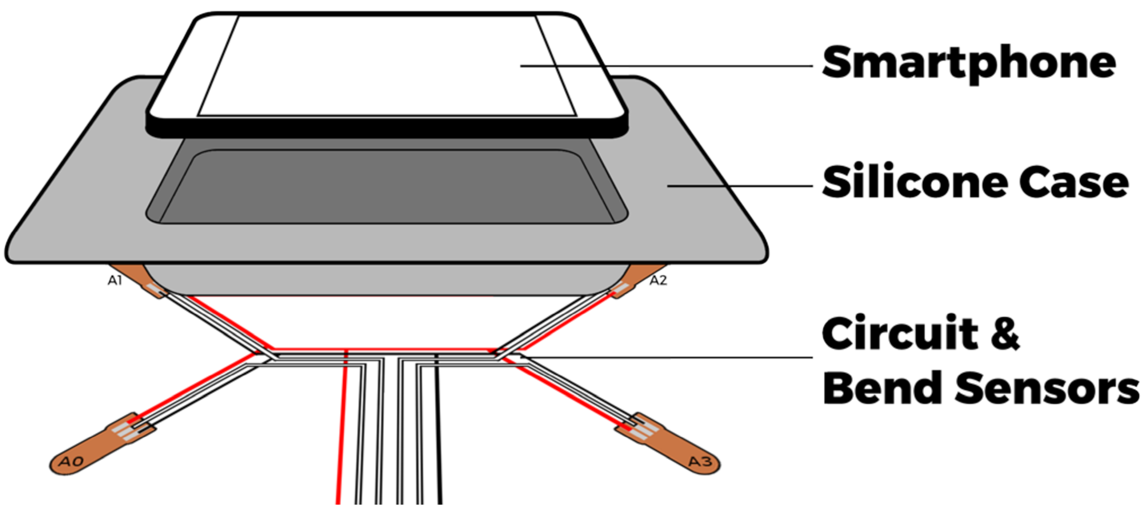

Figure 7: Exploded view of the flexible prototype.

3.2 Apparatus

We built the deformable case in silicone (Alumilte 60A), creating a bezel that was flexible yet retained its shape. We used four 1” FlexPoint bend sensors (Flexpoint, 2016) connected to an Arduino Leonardo (Arduino, 2016) which connected to a Bluetooth module (HC-05 Bluetooth Module, 2016) along with a calibration button to recalibrate the center point of the bend sensors. The Arduino Leonardo read data from each bend sensor and sent the values as a string to the smartphone via Bluetooth. In this setup, the smartphone device and flexible prototype act as two separate units independent of each other. The setup of the experiment is shown in Figure 8.

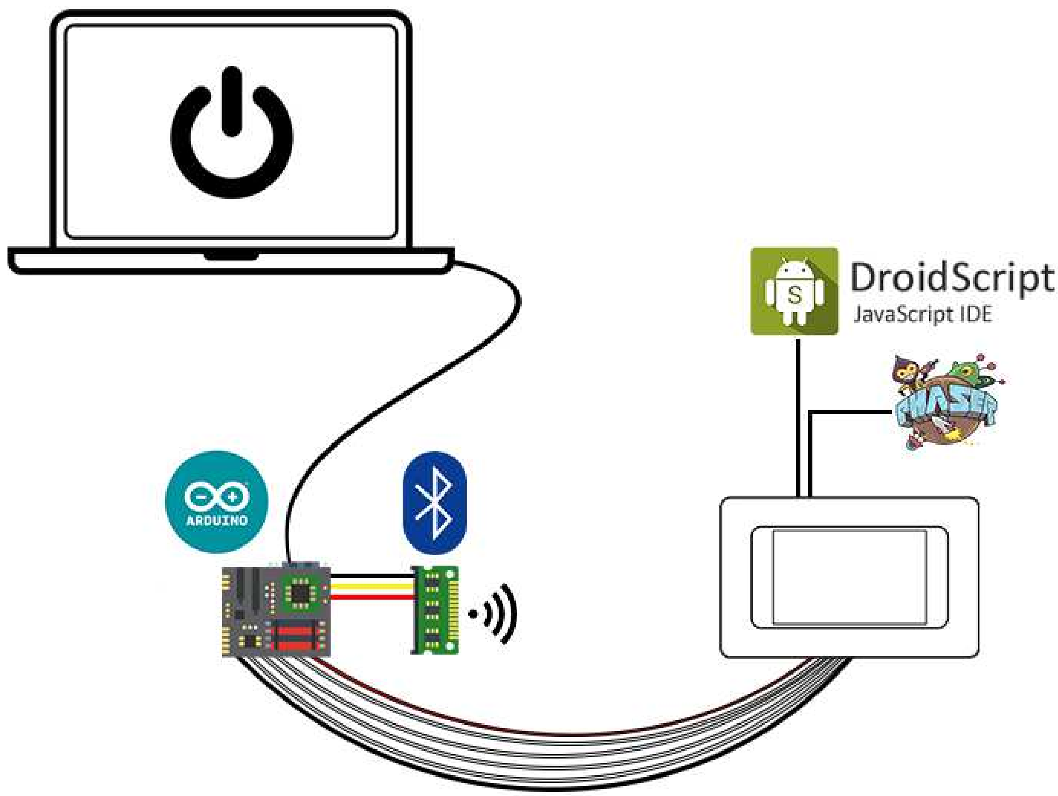

Figure 8: Apparatus of prototype setup; laptop to provide power, Arduino Leonardo to read bend input, Bluetooth Module to send data to device and flexible prototype running DroidScript (reads in data input) and Phaser (mobile game framework).

3.3 Software

Each bend sensor output data ranging from 0 to 1024. A calibration button was used to set the flat state of the sensors because after prolong usage, the bend sensors would remain bent at a certain degree. We used DroidScript (DroidScript, 2015) for building and running Android applications in JavaScript and Phaser.js (HTML5 game framework, 2016) was used to build HTML5 mobile games that could be played using bend gesture inputs. These two applications were used for the software development of the training applications and the Paper Ninja game. DroidScript connects to a laptop or computer via Wi-Fi and allows you to write code in its integrated development environment.

The Arduino board was reading data values from all 4 bend sensors at a rate of 9600 bytes per second (bps). The Arduino sent the data as a string and the DroidScript application parsed the string into an array containing the current state of each bend sensor. This array was then used with Phaser to trigger actions in the game. The DroidScript application also logged all the input data into a text file. The logged data were:

1. Every bend the user performed
2. The length of time it took the user to pass an obstacle
3. The number of bends performed before passing an obstacle
4. The date and time
5. The user id
6. The total time it took the user to complete a trial
7. The order the obstacles were presented in each trial

4 Experiment: Learning and Memorizing Bend Gestures

4.1 Overview

Bend gestures and flexible devices are novel technologies for many users. As such, it would be valuable to examine how people learn and retain these new forms of input. Interacting with these technologies can be both exciting and overwhelming to a novice user (Warren et al., 2013). Thus, we explore whether designers need to include a training module for bendable interactions or not. We believe such training modules could be used until bend gestures become ubiquitous but are not generally needed. A number of prior studies (Ahmaniemi et al., 2014; Kildal et al., 2013) have stated participants describing bend gesture to be a natural form of interaction. We investigate further if users can pick up a deformable device and learn how to use it on their own.

Our main research goal is to determine if individuals require training to learn how to perform bend gestures efficiently. We conducted an experiment to determine how users learn, and become proficient with bend gesture inputs using a handheld flexible device. We examined how the learning time and memorability of bend gestures was affected between three groups of users who were given different levels of training. We provided training through two tutorial applications that allowed users to practice before completing the mobile game. We used the learnability metrics from Grossman, Fitzmaurice and Attar (Grossman et al., 2009) in our examination.

Our secondary research goal was to observe users' memorability. The experiment consisted of two sessions one week apart. The first session compared users' learnability and the second session compared users' memorability of the bend gestures. We wanted to see if there was a difference in memorability between all three user groups. The Guidance Hypothesis (Richard A Schmidt, 1991) states that excessive training, or guidance, can hinder learning and the amount of information retained by a user as the user becomes reliant on the guidance. We would like to validate this hypothesis with regards to interacting with flexible devices.

4.2 Hypotheses

We theorize that training is positively related to learnability and negatively related to memorability based on prior findings. **We hypothesize that the two groups that receive training will show better performance in the learning phase of the experiment which takes place in the first session (H1).** The timing and number of bend gestures performed is expected to be lower for the mapping-trained group and gesture-trained group compared to the non-trained group. **We hypothesize that the mapping-trained group will perform better than the other two groups in the learning phase (H2)** because users are known to learn much better when mapping is part of the training. Users learn better when they see gestures and their mapped actions as opposed to only seeing gestures.

Furthermore, we predict that the non-trained group will perform better than the trained groups in the memorability portion of the experiment (H3). Learning by discovery is likely to yield a higher memorability rate according to the Guidance

Hypothesis (Anderson & Bischof, 2013). It is expected that the changes in participants' performance in the memorability phase would have lower completion times and fewer errors (gestures performed) if users do not have any guidance to rely on.

4.3 Interaction Language

Defining a set of bend gestures was an intricate process because we wanted to create a set of gestures that were not too easy to remember but at the same time not too complicated to perform optimally. We felt that using bend gestures that were easy to remember would defeat the purpose of testing for memorability since there is no difficulty in remembering the bends. Complex tasks were found to be unsuitable for deformable interactions (Eady & Girouard, 2015), therefore, we looked at bend gesture sets used in previous work (Grijincu, Nacenta, & Kristensson, 2014; Lahey et al., 2011; Troiano et al., 2014) and created our own set of bend gesture mappings from those.

In addition to comparing trained and non-trained user performance, we also wanted to study how the two learning methods would affect users' learnability and memorability. We created a set of bend gestures users had to learn and memorize based off of classification schemes proposed by Warren et al. (2013). The bend gestures can be performed using all four corners of the prototype and are grouped into three categories: directional bends, simple one-bend gestures and complex two-bend gestures (Figure 9). The terminology used in the figure to describe the gestures first states the location of the bend, then the direction of the bend and lastly; the action the bend performs in the game. The four corners are described as top-left, top-right, bottom-left, and bottom-right corner. Side bends are performed using the corners adjacent to that side. An up direction indicates a bend performed towards the user and a down direction bend is performed away from the user. There is a total of 11 bend gestures that users can perform. There are 3 directional bend gestures, 4 simple bend gestures and 4 complex bend gestures.

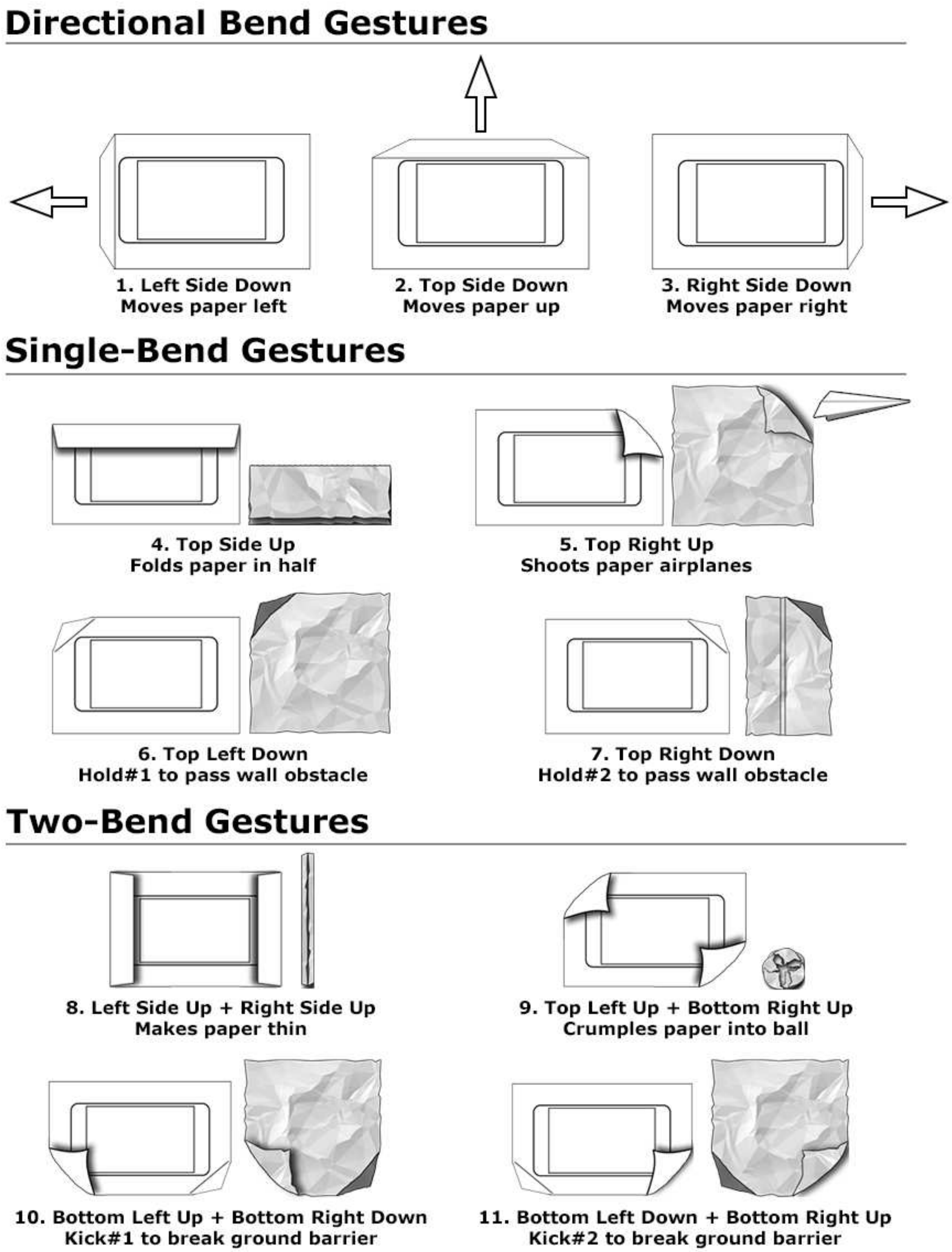

Figure 9: List of bend gestures users must learn and memorize.

These bend gestures were selected because they are simple and basic. Bend gestures contain many degrees of freedom such as location, direction, size, angle, and speed of the bend. This can be overwhelming to the user as it may be difficult to distinguish in practice (Warren et al., 2013). Since human abilities are not as precise when it comes to recognizing small movements in a bend sensor, we felt that using only location and direction would be ideal to examine the learnability of bend gestures similar to those used in PaperPhone (Lahey et al., 2011).

4.4 Game and Training Applications

4.4.1 Paper Ninja Game App

Paper Ninja is a 2D platformer mobile game where the user plays as a piece of paper. The mobile game was built for Android smartphone devices using DroidScript (DroidScript, 2015) and Phaser (HTML5 game framework, 2016). We felt a piece of paper was an appropriate item to represent the flexible prototype as the bend gestures are intended to be feasible on a deformable surface such as a sheet of paper. The goal of the game is to maneuver around obstacles and reach the end of the level to get the paper into a recycling bin. Paper Ninja was created to be played using bend gesture inputs as the game controller. Example screenshots of the game are shown in Figure 10. Ten obstacles required different bend gestures to pass through, including the first screen where the game begins and the final screen where the user must drop the paper into the recycling bin to complete the level.

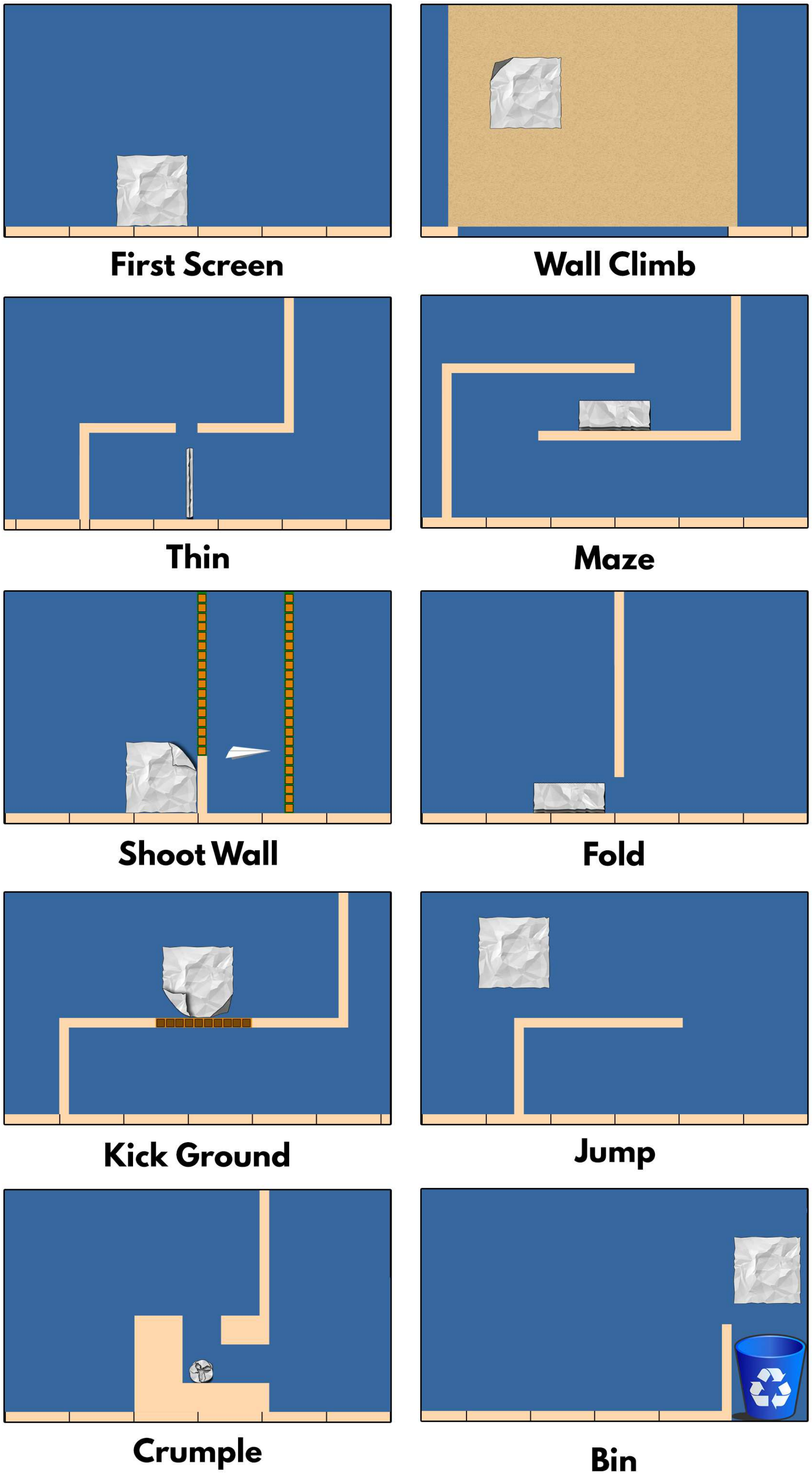

Figure 10: Screenshots of the obstacles in the Paper Ninja game.

4.4.2 Gesture Training App

The goal of the Gesture Training application was to educate the participants of all the possible bends they can perform. The application does not describe what actions the bend gestures are mapped to; the user will need to discover what actions each bend achieves while playing the mobile game. The application displays a piece of paper in the center of the screen while running animation that indicates how to execute the bend gesture and shows the directional arrows as seen in Figure 11. The animation repeats until the user performs the correct bend and a “Good job” message appears or an error message appears instructing the user to “Try Again” if an incorrect bend is registered as shown in Figure 13 E & F. The application does not show the user what the resulting action is, they only see that they performed the bend gesture correctly. When the user completes all possible bends, the process repeats 2 more times. The bend gestures are in random order each trial. Each participant went through the bend gesture trials a minimum of three times or until they felt comfortable.

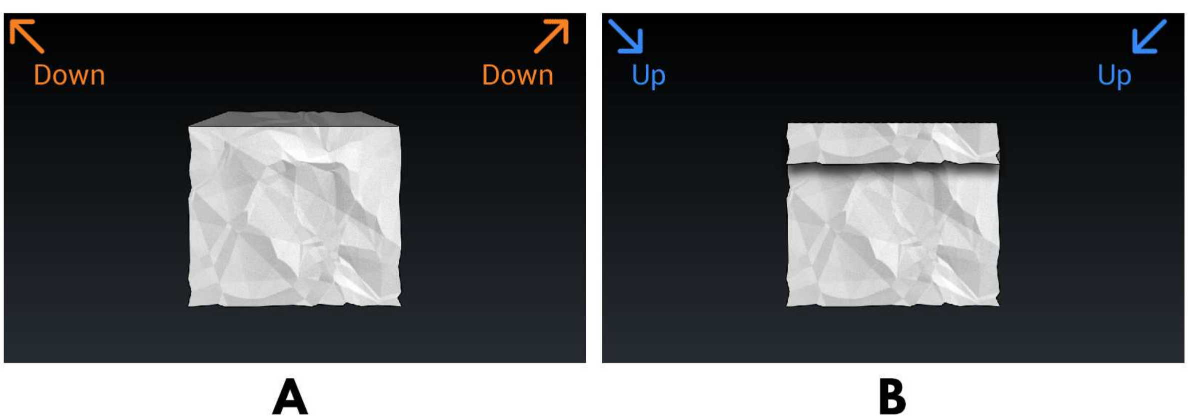

Figure 11: Sample screenshots of the paper bend gestures in the Gesture-Training Application showing a piece of paper with top edge bent. (Full list of bend gestures can be seen in Figure 9.)

4.4.3 Mapping Training App

The Mapping Training Application does everything the Gesture Training application does with the additional purpose of informing the participants what the bend gestures are mapped to. The application first displays a line of text describing which in-game action they will perform and shows arrows in the corresponding corners indicating the directions to bend as seen in Figure 12. Blue coloured arrows were used to indicate upward bends (towards the user) and orange coloured arrows were used to indicate downward bends (away from the user). This colouring scheme was selected following the design choices used by Daliri and Girouard (2016) and Lo and Girouard (2017).

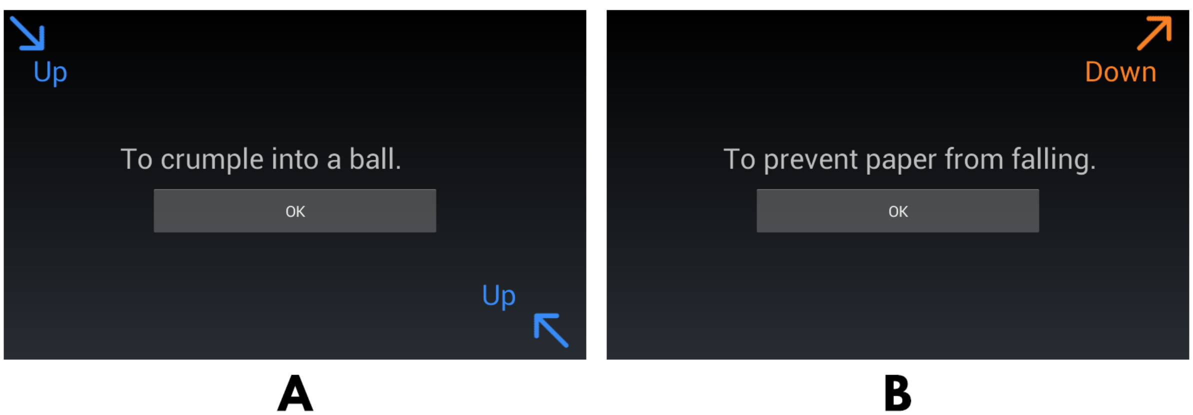

Figure 12: Sample screenshots of the action description in the Mapping-Training Application. (Full list of bend gestures can be seen in Figure 9.)

After the user taps the “OK” button, a piece of paper appears in the center of the screen and loops through an animation sequence showing how to execute the bend gesture as seen in Figure 13. The animation would repeat until the correct bend was performed and a “Good job” message would appear as shown in Figure 13 F. In addition, the application shows the user the resulting action of that bend gesture. An error message appears instructing the user to “Try Again” if an incorrect bend is registered as seen in Figure 13 E. When the input is correct, the application shows the description of the next action to perform and waits for the user to tap “OK” again. The bend gestures are in random order each trial and each participant went through the bend gestures a minimum of three times or until they felt comfortable.

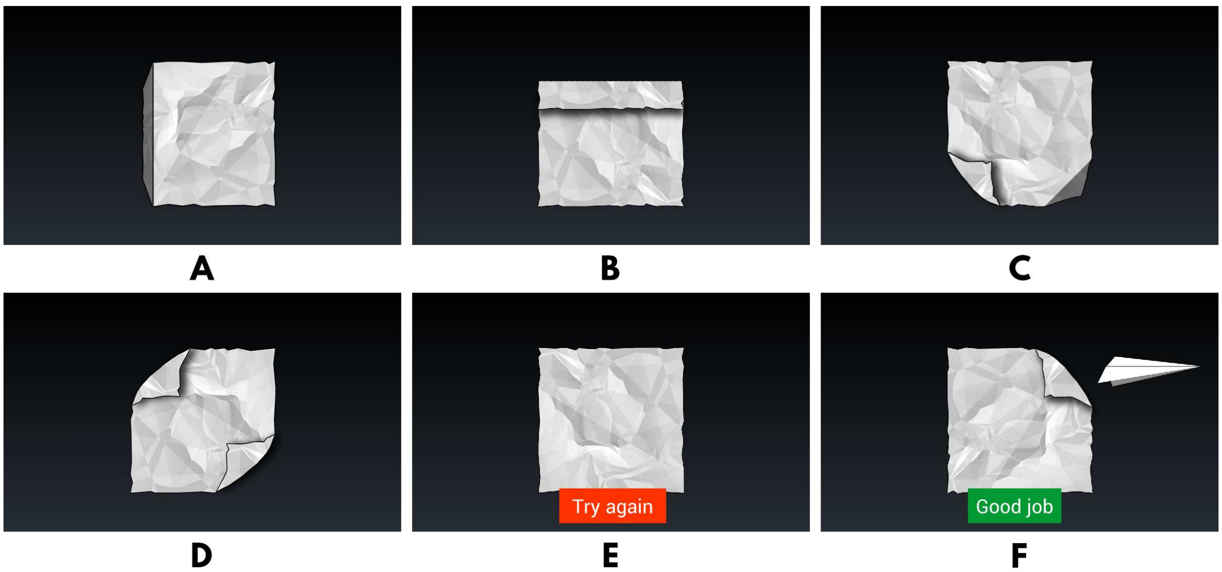

Figure 13: Sample screenshots of the paper bend gestures in the Mapping-Training Application. (Full list of bend gestures can be seen in Figure 9.)

4.5 Participants

The 30 participants (m=19; f=11) had no prior experience with flexible devices or bend gestures. The average age was 23.43 (SD = 4.51; L = 18 H = 31) years old. The participants were randomly distributed between mapping-training, gesture-training and non-training conditions. One participant was left handed and 29 were right handed. All participants owned a handheld smartphone. 8 participants played mobile games once a day, 8 played once a week, 14 played once a month or rarely ever. 5 participants downloaded a new application about once a week or less, 17 download a new application once a month and 8 participants rarely ever download new applications. When participants download new applications, 3 indicated they go through the application's tutorial, 16 do not and 11 said it depends. We compensated participants with $10 cash after they completed the second session of the experiment. We received ethics clearance from CUREB-B (clearance #: 15-289) prior to conducting studies with participants.

4.6 Methods

The study followed a mixed design having both a between-subjects factor and within-subjects. We split participants into one of three training conditions; no-training, gesture-training and mapping-training, creating a between-subject factor. All participants repeated the same game three times in two different sessions creating a within-subjects factor. The independent variable was the amount of training participants received before playing the Paper Ninja game. To evaluate learnability and memorability, quantitative data was gathered by recording the following:

1. The number of bend gestures performed before executing the correct bend to successfully pass an obstacle
2. The amount of time (seconds) it took the user to pass each obstacle
3. The amount of time (seconds) it took the user to complete each trial
4. The total time (seconds) the user took to complete the entire game (all 3 trials)

We took these metrics from Grossman, Fitzmaurice and Attar (Grossman et al., 2009) and used them to compare the performance of the three groups as well as users' performance between the two sessions. We required participants to complete the game three times. We randomly ordered the obstacles every time the game was loaded. We administered a questionnaire (Appendix A) at the end of each session asking users how they felt they did regarding their performance in terms of learning the bend controls and how confident they were in remembering them. Furthermore, to verify what users retained regarding the bend gesture mappings, we asked them to match the action performed to the correct bend gesture (Appendix B). The two groups that received training only went through the training applications in the first session, all three groups went through the same procedure in the second session. We asked participants to think aloud which may have impacted our results by affecting their time as they had to communicate their thoughts to us. However, this only affected a small number of users (2/30) who had to stop playing once to explain their thoughts. Users were told they were being timed and therefore remained their focus on completing their game with no distractions.

The study took place at Carleton University. The first session took approximately one hour in length and the second session was around half an hour in length. We asked participants to sign a consent form prior to beginning the study in the first session. We video recorded both sessions and took notes during the study. All users played the Paper Ninja game using the same flexible prototype with the same bend gesture controls in both sessions. Participants from both trained groups had to complete the training at least 3 times or until they felt comfortable with bend gestures and all three groups had to complete the Paper Ninja game three times.

4.7 Preliminary Study

Before discussing the results of the methodology above, we would like to state that this is the second iteration of the experiment. We ran into a series of issues with the study the first time around (called here after the preliminary study), and we had to discard the data (28 participants) and start over the data collection after fixing the source of the problem. We report here the history of this preliminary study, issues and solutions implemented. Our issues were due to an unreliable prototype, an unclear training application, and flaws and bugs in the implementation of the Paper Ninja game and data logging.

4.7.1 Prototype Issues

The design we used consisted of 2 sensors in each corner resulting in 8 sensors in total (p. 17 Figure 5 Version 3), all sensors were covered with black duct tape. This created a thick and uncomfortable prototype for users to hold and use. The tape was intended to hold the sensors in place but due to bending, the tension on the sensors caused them to deteriorate quickly and become unstable. An unstable sensor would generate readings of up to 14.5 bend gestures per second (1120 gestures performed in 77 seconds). We decided it would be better to augment one bend sensor in each corner and to hold them in place using fishing wires rather than duct tape as described in Section 3.1.3.

4.7.2 Training Issues

We originally ran this study using two user groups; gesture-trained and non-trained. The gesture-training application was similar to the current gesture training application but there were no corner arrows to indicate which direction to bend to. Users said they were not aware of what the bend actions were being mapped to. Though Figure 13 F displays a paper airplane, users would tend to miss such images. We improved the training application by adding directional arrows and created a second, more informational training application to show the user the mapping of each gesture.

4.7.3 Game Issues

The initial game allowed users to fall off the map during the wall climb obstacle and effectually trigger a “game over” action, effectively restarting the game. The issue with this is that every time the game would restart, it would increment the trial number count and load the obstacles in a new randomized order. This means that users could now see some obstacles for the first time and some for the second time: however, all data being logged would indicate this is the user’s second time viewing each obstacle. In addition, users could move left at the start of the game or jump past the bin in the end both resulting in the user falling off the map. We fixed these three problems by resetting the paper’s position in the map when it falls off.

Users could also fold into any paper shape regardless of what shape they were in. This means the user could crumple into a ball and then directly fold into a thin piece of paper. There were many instances where the user would fold the paper to pass under an obstacle and while performing the correct move gesture, the paper would fold into another shape due to small unintentional bends. This led to two major issues; one, it confused the users and led them to learn incorrect bend gesture mappings. Second, it led to an extremely high number of bend gestures which was an inaccurate representation of the real number of gestures the user attempted in the game. This was fixed by forcing users to “unfold” after performing any bend. Therefore, when a user crumpled into a ball, they had to un-crumple before being able to bend into another shape.

Breaking the ground (Figure 10 Kick Ground) and shooting the wall (Figure 10 Shoot Wall) also created confusion. Users had to shoot paper airplanes to break a wall and when users shot paper airplanes at the beginning of the level, the airplanes would move right and go through the entire level meaning they would eventually reach the brick wall and break it before the user reached that obstacle. The user would approach the “shoot wall” obstacle which was already destroyed and the user would not know which bend gesture allowed them to pass this obstacle. Then when they came across it in the second trial, it would be as though they saw it for the first time. We fixed this by making the game wait until the player’s position was close to the wall before letting paper airplanes break it.

The kick-ground obstacle had the same issues. To break the ground, users had to bend both bottom corners of the prototype in opposite directions. The game was programmed to listen for those bends and then break the ground. However, the ground would break when users performed those bend actions from anywhere in the game which resulted in the obstacle being broken when the user arrived to it. This was fixed by requiring the user to position the paper atop the brick ground first before listening if the bottom corners were bent correctly.

To summarize, the preliminary study let us to identify many issues that we fixed for the current study, including improving the game by preventing trials from restarting if the player falls off the map, improving the training applications by adding directional arrows and creating a more stable, robust prototype that logged data more accurately. We used the newly collected data in our results and discussion.

4.8 Results

The descriptive statistics associated with each group's timings and gestures are shown in Figure 14 and Figure 15 respectively.

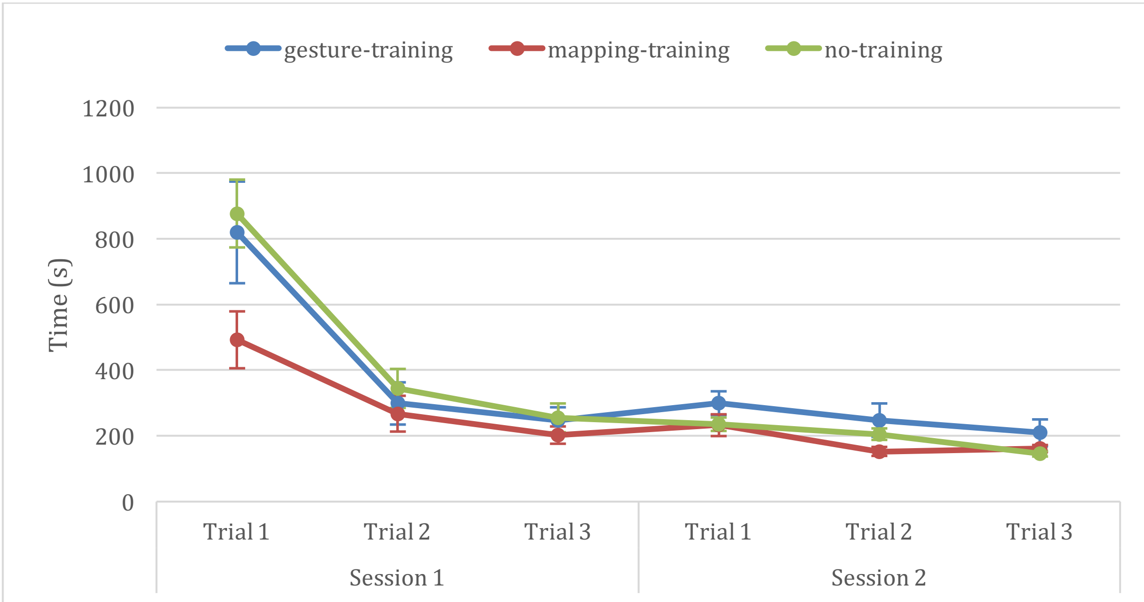

Figure 14: Completion time (seconds) of each group. Error bars indicate standard deviation

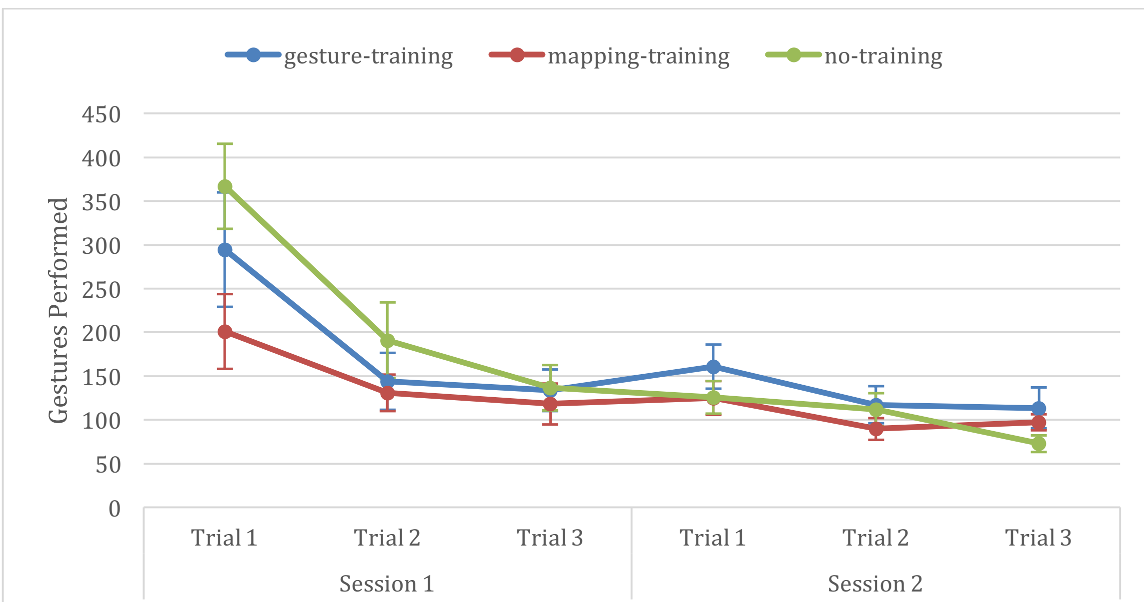

Figure 15: Number of gestures performed by each group. Error bars indicate standard deviation

The results section is broken down into 3 main parts; session 1 results, session 2 results and the post experiment qualitative data. In both the session results sections, we conducted between-subject tests to find differences between the groups and then within-subject tests to see how each group progressed. We analyzed the total time (in seconds) it took to complete each trial and the total number of gestures performed by each group in each trial. A Shapiro-Wilk's test and a visual inspection of their histograms, normal Q-Q plots and box plots showed a normal Gaussian distribution for the data values for all three groups in both sessions. We evaluated the assumption of normality and determined it to be satisfied as the skew and kurtosis of the three groups' distributions were less than absolute 2 and absolute 9 respectively (Schmider, Ziegler, Danay, Beyer, & Bühner, 2010).

To test the effect of each condition (gesture-trained, mapping-training, non-training), we first ran a mixed factorial ANOVA using the factors sessions and trials as repeated measures within-subjects and the group's training levels as the independent variable for between-subject design. To evaluate the survey responses between all three groups, we used a Friedman test. We used Cohen's d to indicate the effect size of every significant comparison (post-hoc) we found in the context of an ANOVA. The effect size is small if $d = 0.2$, medium if $d = 0.5$ and large if $d = 0.8$.

4.8.1 Session 1: Learning Phase

In the first session, we measured the time it took participants to complete each trial and the number of gestures performed in each trial. A mixed factorial ANOVA yielded a statistically significant effect in trial 1 for both time ($F(2, 27) = 7.63$, $p = 0.002$) and number of gesture inputs ($F(2, 27) = 6.14$, $p = 0.006$). To evaluate the nature of the differences between the groups' means further, we conducted a one-way ANOVA test with three Fisher's LSD post-hoc tests. We associated that higher time and number of gestures to lower performance. A lower completion time and lower gesture count means the participant knew what they were doing and knew how to pass each obstacle in a proficient manner.

For the completion time in trial 1, we found statistically significant difference between the gesture-trained group and the mapping trained group ($F(2, 27) = 7.63$, $p = 0.005$, $d = 1.30$) and significant difference between the mapping-trained group and the non-trained group ($F(2, 27) = 7.63$, $p = 0.001$, $d = 2.02$), but we saw no significant difference between the gesture-trained group and the non-trained group. When comparing the number of gestures performed in trial 1; we only found significant difference between the mapping-trained group and the non-trained group ($F(2, 27) = 6.14$, $p = 0.002$, $d = 1.82$). For trials 2 and 3 of session 1, we found no statistical significant differences between the three groups with regards to both timings or number of gestures.

We performed a one-way within-subjects ANOVA to see how much each group improved in session one. We compared the first and last trials to evaluate the learning curves of each group. All three groups reduced their completion time and number of gestures performed. The difference between trial 1 and trial 3 of each group are shown in Table 1.

Table 1: Changes between trial 1 and trial 3.

Training	Time (s)	Number of Gestures
Gesture	Decreased, $F(1, 9) = 47.72$, $p = 0.00$	Decreased, $F(1, 9) = 26.37$, $p = 0.001$
Mapping	Decreased, $F(1, 9) = 36.10$, $p = 0.00$	Decreased, $F(1, 9) = 12.82$, $p = 0.006$
Non	Decreased, $F(1, 9) = 141.34$, $p = 0.00$	Decreased, $F(1, 9) = 103.54$, $p = 0.001$

We see that training had an effect on users' performance. The mapping-trained group performed the best overall and there was no significant difference between the non-trained group and gesture-trained group.

4.8.2 Session 2: Memorability Phase

An independent between-groups ANOVA found a statistically significant effect in session 2 trial 1 for time ($F(2, 27) = 3.79$, $p = 0.035$) but we found no significant difference with regards to the number of gestures performed by each group.

In terms of completion time for trial 1, a one-way between-groups ANOVA found the difference between the gesture-trained group and the mapping-trained group to be statistically significant ($F(2, 27) = 3.79$, $p = 0.022$, $d = 0.97$) and between the gesture-trained group and the non-trained group as well ($F(2, 27) = 3.79$, $p = 0.028$, $d = 1.07$). There were no significant differences between the mapping-trained group and the non-trained group and no differences between any of the groups in terms of bend gestures performed. In trial 2, we only found a significant difference between the completion times of the gesture-trained group and the mapping-trained group ($F(2, 27) = 5.58$, $p = 0.002$).

Looking at the end of session 2, in trial 3 we found that the non-trained group had a significantly lower completion time than the gesture-trained group ($F(2, 27) = 4.38$, $p = 0.009$, $d = 1.07$) and significantly lower gesture count than the gesture-trained group ($F(2, 27) = 4.30$, $p = 0.007$, $d = 1.13$). In addition, the gesture-trained group also performed significantly worse than the mapping-trained group ($F(2, 27) = 4.38$, $p = 0.039$, $d = 0.81$) in terms of completion time but between the two groups. No significance was found for the number of gestures performed in trial 3.

To evaluate the memorability, we compared trial 1 of session 2 to trial 3 of session 1, since it is their first time attempting to recall the bend gestures. We wanted to verify if training is negatively related to memorability and a visual inspection indicates both trained groups performed worse than their previous session and the non-trained group was the only group that improved in performance (lower completion time and gesture count). The only significant difference was found in the gesture-training group's completion time, which validates the Guidance Hypothesis. The performance changes in the mapping-trained group and gesture trained group were not significant.

We looked at the differences across each group's performance by running a one-way within-subjects ANOVA to see how much each group changed between their first session and second session. The difference between the sessions are shown in Table 2.

Table 2: Changes between session 1 trial 3 and session 2 trial 1.

Training	Time (s)	Number of Gestures
Gesture	Increased, $F(1, 9) = 23.66$, $p = 0.001$	n. s.

Mapping	n. s.	n. s.
Non	n. s.	n. s.

In session 2, the non-trained group performed similarly to the mapping-trained group. We see that gesture-training had negative effects on the performance of users in that group. The mapping-trained group performed the best overall indicating that good training is beneficial but bad training is worse than no training.

4.8.3 Post Experiment Questionnaire

4.8.3.1 Session 1 Responses

We ran a Wilcoxon test to evaluate the responses from the questionnaire and found only one statistically significant difference among the responses of the groups. Users from the gesture-trained group had significantly lower confidence in how they felt they performed compared to the mapping-trained group ($Z = -2.23$, $p = 0.039$) and the non-trained group ($Z = -2.41$, $p = 0.016$) as shown in Figure 16. The following responses are shown in the subsequent figures.

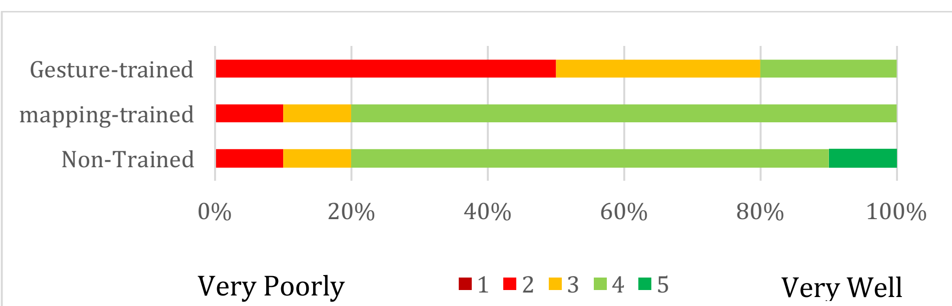

Figure 16: Percentages of participants' responses when asked in session 1: How do you feel you did regarding your performance?

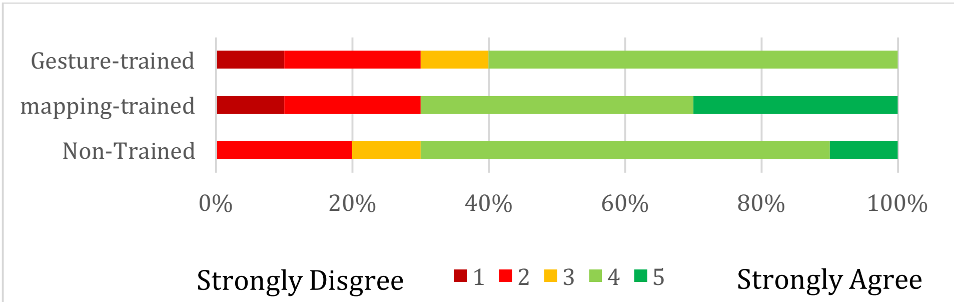

Figure 17: Percentages of participants' responses when asked in session 1: How much users agree with "I found it easy to learn the bend gestures and controls."

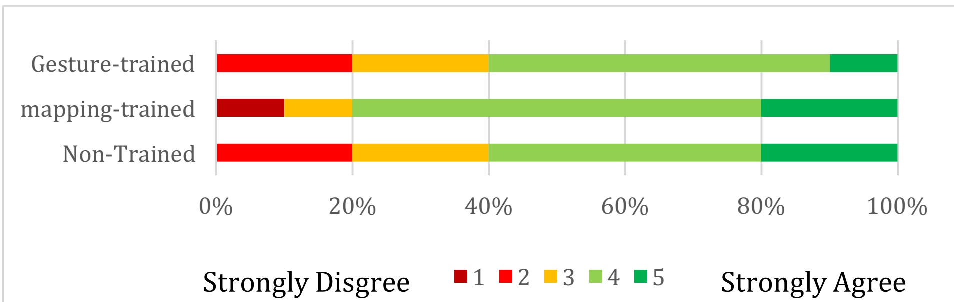

Figure 18: Percentages of participants' responses when asked in session 1: How much users agree with "I am confident that I can remember these bend gestures and controls."

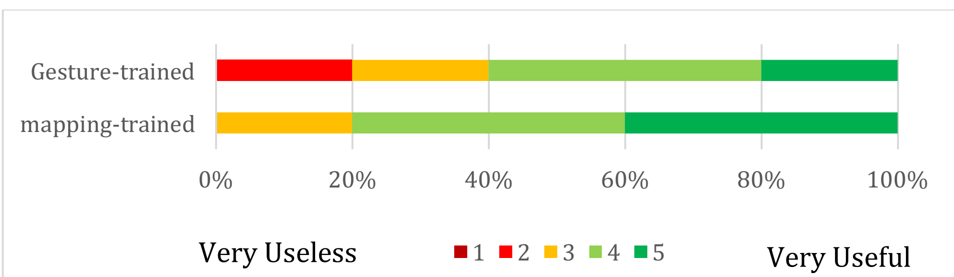

Figure 19: Percentages of participants' responses when asked in session 1: How useful did you find the training to be?

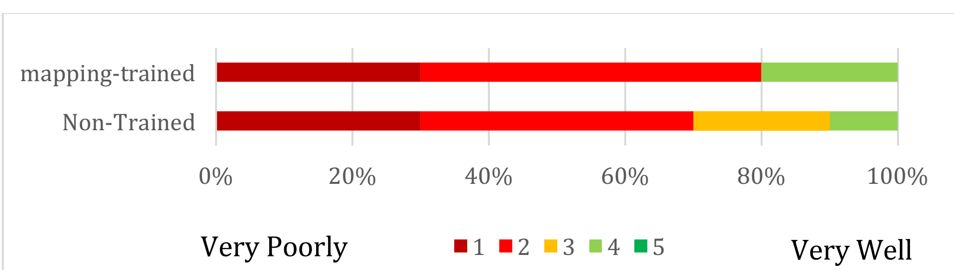

Figure 20: Percentages of participants' responses when asked in session 1: How well do you think you would have done without training?

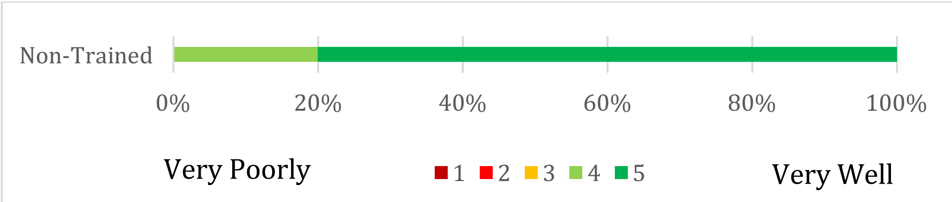

Figure 21: Percentages of participants' responses when asked in session 1: How well do you think you would have done with the help of training?

4.8.3.2 Session 2 Responses

A Wilcoxon test revealed no statistically significant difference among the responses in session 2. The responses are shown in the following figures.

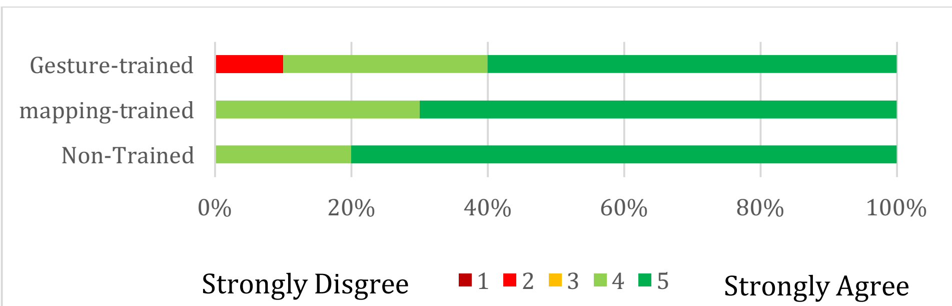

Figure 22: Percentages of participants' responses when asked in session 2 how much users agree with "It was easy to recall (remember) the bend gestures and controls."

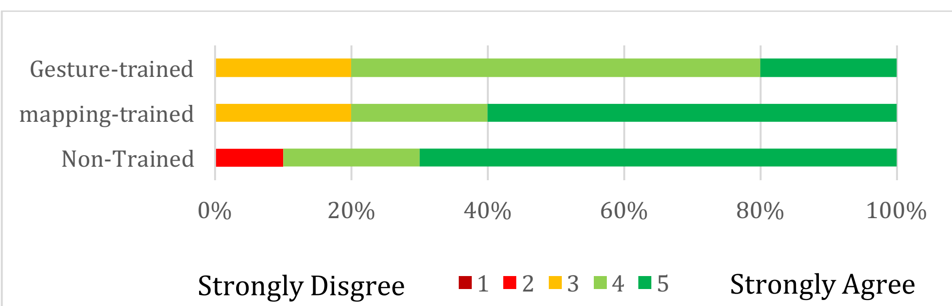

Figure 23: Percentages of participants' responses when asked in session 2 how much users agree with "I performed better than I expected."

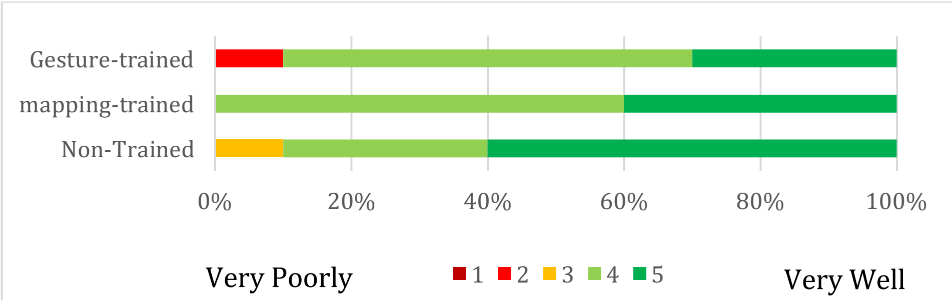

Figure 24: Percentages of participants' responses when asked in session 2: How do you feel you did regarding your performance?

4.8.3.3 Gesture Mapping Responses

At the end of each session, we asked users to identify which bends mapped to which actions to authenticate their knowledge of the bend gesture mappings. The results of the responses (Appendix B) show that every group's knowledge of the bend gesture mappings improved except for how to pass the Crumple Obstacle.

4.9 Discussion

We observed and analyzed our quantitative and qualitative data to gain understanding on the learnability and memorability of using flexible devices in gaming. In this section, we discuss the results and extract our main findings.

4.9.1 Effects on Learnability

Training helped users with their performance initially but ultimately all three groups reached the same level of performance with no significant differences by the end of the first session. Nonetheless, our findings partially confirmed that training is positively related to learnability (H1). The training we provided made a significant difference in trial 1 of session 1 with the exception of the completion time of the gesture-trained group who matched that of the non-trained group. The non-trained group did not know of any bend gestures and therefore spent most of the time discovering each gesture and problem-solving their way through the game the most; this led to users retaining a high amount of information based on their results in session 2. Additionally, users commented that the obstacles which took the longest time to figure out how to pass became the most memorable and easiest to recall.

Gesture-training had no positive effect on users' completion time since they performed similar to the non-trained users. This matches the research of Anderson and Bischof (2013) who stated that learning should involve mapping between the gesture and the resulting action. Because we deprived the gesture-trained group of the mapping, it seemed to have confused them. Even though they performed less gestures than the non-trained group, they still needed the same amount of time as the non-trained group to think of what they should do to complete the game. This could be because users spent time trying to remember what gestures they saw instead of attempting bends to pass the obstacle. The mapping-trained group performed significantly better in both the completion time and gesture count in trial 1 of session 1; this supports our second hypothesis that mapping training is better for learnability (H2).

Our participants had no prior experience to using bend gestures. This meant that while playing Paper Ninja, users were learning 2 things; how to play the game and how to perform bend gestures. Performing bends was a new concept to the participants thus our results could have been different had we used users who had experience with flexible devices. The effects of our training on users would have been different if bend gestures were more familiar to them. Users who are acquainted with bend gesture interactions may be affected differently by training regardless of the application. This introduces an opportunity to further research the effects on learnability of new applications with users who have had experience performing bend gestures using flexible devices.

Users mentioned there were too many gestures to learn at once, they would have preferred to learn them gradually as they progressed through the game. Many users from the gesture-trained group voiced that they would have liked to have a gesture to action mapping in their training. Even so, user 12 stated, “The tutorial [mapping-training] was good for outlining what I was able to do with the new technology, however most of the learning was done in game by experimenting.”

4.9.2 Effects on Memorability

We looked at how each group performed in session 2 and compared it with their last trial of session 1 to verify if training is negatively related to memorability. While it was not found to be significant, we found that the non-trained group was the only group to improve their results in the first trial of session 2. The non-trained group performed significantly better than the gesture-trained group in trials 1 and 2, and the mapping-trained group performed significantly better than the gesture-trained group in all 3 trials. We observed that gesture-training had a negative effect on memorability since the gesture-trained users spent longer time trying to recall the bend gestures and had a higher error rate (performed more gestures). This only partially validated our third hypothesis (H3) since the mapping-trained group and non-trained group had no significant differences. Users felt that gestures with natural mapping (folding, moving) were easier to remember compared to gestures whose mappings were not transferable to paper (shooting paper airplanes).

We noticed that users who played mobile games found it easier to remember the bend gestures. While this was not formally analyzed, it might indicate that users who are accustomed to frequent in-game interactions may not be affected by training of new interactions. Furthermore, users indicated that playing as a piece of paper helped recall the bend gestures since it was mapped directly to performing bends on real paper. Bend gestures mapped to natural actions such as folding, appeared to be easier to recall and the more complex gestures were harder to recall. Many non-trained users commented they “thought they would forget the gestures but didn’t.”

4.9.3 Prototype Design

We thought that we had designed a prototype that provided users with a sufficient anchor point to use when performing a bend. We anticipated that the rigid screen would be leveraged as a surface that users can use to apply a force on to prompt a bend. Surprisingly, users still commented about the lack of an anchor point. This was mainly due because they were unaware of how to hold the prototype. Our prototype was compared to a traditional video game controller. Users stated that the prototype could be more ergonomic and fit their hands better as opposed to being flat and requiring them to hold the device awkwardly. Research in the anthropometrics of human hands would provide insight as to how users hold devices based on the device size and shape.

Users mentioned that our device was too big and thus awkward to hold. In addition, some users indicated their hands were sore after playing the game due to the stiffness of the material. This is interesting because in our observation of the prototype we noticed that the corners did not always return to their original flat state. This would indicate that the material was not stiff enough, contrary to how users felt. This was due to the material absorbing heat from the user's hands after being used for some time causing a "melting" affect. There were times when the user had to straighten the corner to unbend a sensor. Only users who had noticeably smaller hands commented that the device was too big.

4.9.4 Observations of User Behavior

We observed interesting behavioral patterns across many users. When users learnt of a bend gesture, they would use it as many times as they could to pass as many obstacles as they could instead of uncovering all 11 available gestures. For instance, users that discovered folding the paper (Figure 9 Bend 4) kept using folding whenever they could, others those that discovered crumpling (Figure 9 Bend 9) first used crumpling as many times as they could. This was a wise method to completing the trials quicker which essentially reduced the user's completion time however it somewhat defeated the purpose of the study. Prior to starting the task, participants were told that each obstacle has a bend gesture associated to it, some users noticed themselves using the same gestures and decided to stop and take the time to learn what the optimal gesture was for each obstacle; this also affected the completion time by increasing it. In this case, training could help with bend gestures because it would inform the user of all the available bends allowing them to complete tasks more efficiently by performing the more suitable bend at each obstacle. Other cases where training would be advantageous is if the user had a limited number of tries to complete a task or if the study is not focused on learnability but other metrics such as enjoyment and ease of use. In that case the researcher would be interested in the user's qualitative input after completing their tasks to get their feedback on their experience. In this case, objective measurements are not needed to determine a user's enjoyment therefore training would have no effect on the results. Some obstacles were passed with the same gesture due to glitches in the game, fixing these glitches would reduce the use of repeated gestures in the game. We could have had in-game training by showing the intended gesture at each obstacle but this would have added an additional layer of training on top of that of which we were measuring and comparing.

Users commented that the thin obstacle (Figure 10 Thin) was hard to perform because it required all 4 corners to be bent and the kicking obstacle (Figure 10 Kick Ground) was hard because it required bending the bottom corners. Several users found it difficult to bend the bottom corners, one user held the device upside down when they had to bend the bottom corners so they can perform the bends. Many users felt awkward when holding the device. They voiced their dislike of its big size and some (5/30) kept it placed on the table and only bent the necessary corners to interact with it as opposed to holding it in their hands. Some users did the same thing to avoid unintentional bends.

In our observations, we noticed that users had no problem bending the top corners but the bottom corners required more focus and effort to bend correctly. Many users voiced their dislike of performing bottom corner bends. The top corners are the preferred and simplest corners to bend. We found that the top corners should be kept for more primary actions and the bottom corners should be used for secondary actions, such as right click and left click of a computer mouse.

In general, users had a positive experience with the flexible prototype and the bend gestures we designed. Many users said playing the game was intuitive and fun. Users mentioned that the bend gestures made sense and the more they understood how they work the more intuitive and natural the gestures became. These comments are similar to those collected by Nacenta et al. (2013) who felt that their user-defined gestures were more fun and effortless to do. In both cases, the gestures that were more memorable were the ones that were fun and natural.

4.10 Summary and Recommendations

We evaluated the effects that training had on learnability and memorability using a mobile game and three different conditions. In conclusion, our qualitative data showed that training has some effect initially but eventually the same performance was reached without any training. Furthermore, our data partially validated our third hypothesis (h3) since the mapping-trained group and non-trained group performed the same in session 2 and the non-trained group performed significantly better than the gesture-trained group in trial 1 and 2 of session 2 in terms of completion time.

Users felt that some bend gestures were natural and therefore easy to learn and the unnatural gestures were hard to learn. Users commented that the obstacles that took the longest to pass in the first session became the easiest to remember in the second session. Users from the gesture-trained group struggled the most in terms of recall time and commented that they would have liked to see a gesture to action mapping during their training.

We believe our results are generalizable in the context of a mobile game that requires simple interaction. Our research consisted of observing users learning a new method of interaction and using technology that is new to them. In doing so we saw that users who had to memorize bend gestures (gesture-trained) performed worse than users who learnt by understanding bends and what they are used for (mapping-trained and non-trained). The gesture-trained group felt like they had to memorize all the gestures and then use what they could remember to complete the task. The other two groups saw the context in which the gestures will be used in and thereby performed better; this approach can be applied to other mobile games. Users indicated that learnability and memorability of bend gestures was associated with how much time and effort they spent to learn the correct bend gesture. However, complicated gestures are expected to bring the user to a quitting point since they will run out of bends to try and can only rely on training, or guidance, to move forward. Therefore, a complex application such as a word editing application will still require training for its users.

We propose the following recommendations for future work with flexible devices:

1. **Training modules are not needed in the context of games**

   Though training did help initially, it eventually became irrelevant and unnecessary. Users spent time going through bend gesture training but reached the same performance as users who did not spend any of their time training. Therefore, no training is needed for interactions requiring simple tasks.

2. **If training is provided, map the gestures to the actions**

   If an application requires some sort of training, we recommend that the training make the gesture to action mapping as clear as possible. In addition, users stated there were too many gestures to learn at once. Therefore, we recommend to not show all the gestures one after the other, let the user experience the gesture in its intended context. However, this is not an area that we studied in-depth.

5 Conclusion

In this thesis, we presented a study into training effects on learnability and memorability of bend gestures. We began by designing a new flexible prototype that encased a rigid smartphone and allowed for bend gesture inputs. We also created Paper Ninja; a 2D platformer mobile game that can be played using bend gesture inputs with our flexible device. We implemented a methodology to test what effects training had on users' performance in terms of completion times and gestures performed. We observed users playing Paper Ninja three times across two sessions (session 1 and 2) one week apart.

Our results showed that mapping training yields the best performance compared to gesture-training and no-training but then has no significant effect afterwards. We observed partial validation of the Guidance Hypothesis when the gesture-trained group performed significantly worse in their completion time in session 2. While our results showed that participants from all three groups could recall the gestures seamlessly, we confirm our initial hypothesis that training is positively related to learning. In addition, there was an overall agreement that bend gestures are an intuitive and natural form of interaction in gaming. We believe as flexible displays improve in the future, they will be used more and more with games.

5.1 Limitations

Our research began as an explorative process and thus, our hardware, software and methodologies were new procedures. Instead of using a real flexible display, we resorted to augment a rigid smartphone onto silicone. The bend sensors were fragile and would break after excessive usage, requiring us to constantly replace them with new ones in between study sessions. While our prototype provided users with a stimulating experience, both the hardware and software were not able to accommodate the unpredictable differences in user performance. Depending on how the user held the prototype, some participants would perform large bends and pass the threshold that was set on the sensor, thus unintentionally creating unwanted bends, while others would perform small bends that did not activate the sensors due to not passing the threshold. The bend sensors were unstable and would easily oscillate in their readings regardless of the calibration and threshold set on them. This lead to some confusion for the participants. For instance, if they performed the correct bend gesture but did not pass the bend sensor threshold, then they would not see a response in the game and associated no in-game action to that gesture. Additionally, users would sometimes perform the correct bend but the software response would lag. This means that by the time the user tried another bend gesture, they would have seen the result of their previous bend gesture and mapped that action with the wrong gesture. Having a faster response time in the software would solve that issue. Nevertheless, we did manage to collect useful data and identify usability requirements for future work.

We had a total of 30 participants in the study. Our study was a mixed between-subject design with three different conditions therefore we only had 10 participants per condition. This is a low number; we feel that more participants would have given us a more accurate distribution of our data points and we would have had a better understanding of whether our outliers were indeed outliers or negligible. In our data logging methods, we wanted to log every bend gesture the users perform. However, this was not done properly, instead of logging every corner that was being bent, we only logged which gesture set was being performed. For instance, bending the top left corner up did not do anything in the mobile game (not part of our gesture set) therefore it was not logged when the user performed that bend.

Another limitation to our experiment was the inability to track time accurately. Some users would begin a trial, which started the in-game timer, and then stop playing at random times to describe to us what they are thinking. Thus, the method of thinking aloud could have skewed the completion times of our results.

5.2 Future Work

We believe bend gesture interaction has a promising future in gaming. Our study explored an innovative way of playing mobile games using bend gesture inputs. Users gave positive feedback and had a good experience in using our flexible prototype. We would like to explore further studies using real flexible displays or other flexible concepts. We only observed two different training modules hence it would be interesting to implement novel ways of training users and seeing how those effect user performance. One example would be to provide in-game training. Thus, as the user progresses through the first level, they can see what gestures need to be performed and in which context they are to be used in. This level of training may yield better results than our training methods since users can then associate each gesture to the obstacle in the game.

The game we created was specifically designed to directly relate to a flexible prototype. Playing as a piece of paper made it more natural to perform bend gestures just as a person would with a real piece of paper. As a result of using a virtual piece of paper, it may have made it easier for users to learn and recall bend gestures. Future work would include new and different games, or existing mobile games that do not have any correlation to a flat bendable surface. We believe it would be important to conduct future in-depth work into the effects of training for such games.

Appendices

Appendix A

Questionnaires

A.1 Session 1: Pre-Test Questions

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Pre-Test Questionnaire

The information provided here will be held completely confidential.

1. User ID?
2. Training Group?
3. What is your age?
4. What is your sex?
   - Male
   - Female
5. What is your dominant hand?
   - Right-handed
   - Left-handed
   - Both/either
6. Do you own a smartphone?
   - Yes
   - No
7. How big is your smartphone screen (size of display in inches)?
8. How often do you play mobile games?
   - Once a day
   - Once a week
   - Once a month
   - Never play games
   - Other: ______________
9. How often do you download new applications?
   - Once a day
   - Once a week
   - Once a month
   - Rarely download new apps
   - Other: ______________
10. When you download a new application, do you go through the tutorial? Please comment why/why not?
    - Yes
    - No
    - Sometimes
    - Comment: ______________

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A.2 Session 1: Post-Test Questions

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Session 1 Post-Test Questionnaire

The information provided here will be held completely confidential.

1. I found it easy to learn the bend gestures.

1 Strongly Disagree	2	3	4	5 Strongly Agree

2. I am confident that I can remember these bend gestures.

1 Very Poorly	2	3	4	5 Strongly Agree

3. How do you feel you did regarding your performance? (i.e. In terms of learning the bend gestures and performing the correct bends)

1 Very Poorly	2	3	4	5 Very Well

4. How useful did you find the tutorials and practice material to be?

1 Very Poorly	2	3	4	5 Very Well

5. Depending on trained user or non-trained user:
   a. How well do you think you would have done without a tutorial or practice material?
   b. How well do you think you would have done with the help of a tutorial? (compared to how you did without a tutorial or practice)

1 Very Poorly	2	3	4	5 Very Well

6. Do you have any other feedback or comments?

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A.3 Session 1 & 2: Action-Gesture Questions

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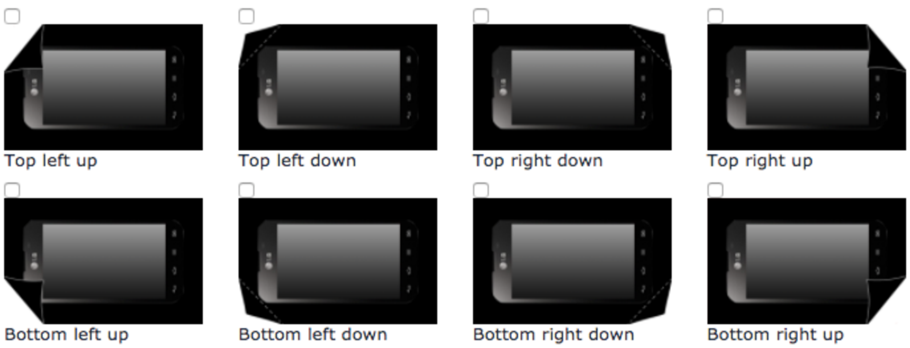
Action Gesture Questionnaire

The information provided here will be held completely confidential.

The following multiple choice answer was given for each question listed below.



1. What bend gesture(s) made the paper jump up?
2. What bend gesture(s) made the paper be thin?
3. What bend gesture(s) made the paper fold in half?
4. What bend gesture(s) made the paper crumple into a ball?
5. What bend gesture(s) did you use to pass the wall?
6. What bend gesture(s) did you use to break the ground obstacle?
7. What bend gesture(s) did you use to shoot paper airplanes?
8. What bend gesture(s) made the paper move left?
9. What bend gesture(s) made the paper move right?

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A.4 Session 2: Post-Test Questions

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Session 2 Post-Test Questionnaire

The information provided here will be held completely confidential.

1. User ID?
2. Training Group?
3. It was easy to recall (remember) the bend gestures and controls.

1 Strongly Disagree	2	3	4	5 Strongly Agree

4. I performed better than I expected.

1 Strongly Disagree	2	3	4	5 Strongly Agree

5. How do you feel about your performance? (i.e. in terms of remembering the bend gestures and performing the correct bends)

1 Very Poorly	2	3	4	5 Very Well

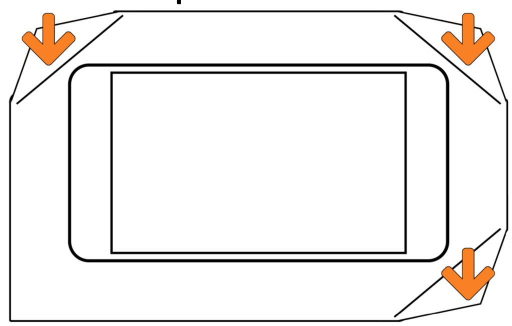
6. Do you have any other feedback or comments?

Page **1** of **1**

Appendix B

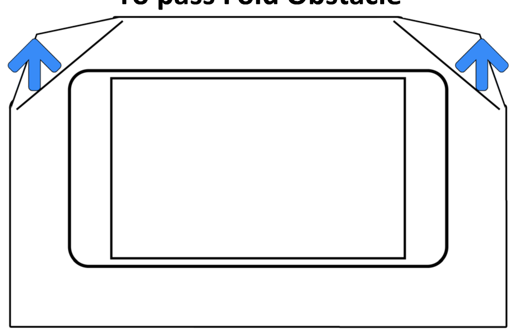
Responses of users indicating the bends they performed to pass an obstacle in the Paper Ninja game

To pass Wall Climb



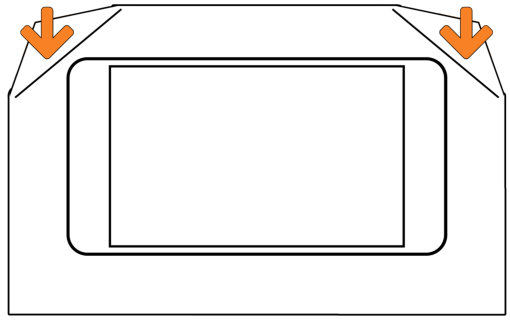
	Gesture-Training	Mapping-Training	No-Training
Session 1	96.25% Correct	91.25% Correct	76.25% Correct
Session 2	98.75% Correct	97.50% Correct	100% Correct

To pass Fold Obstacle



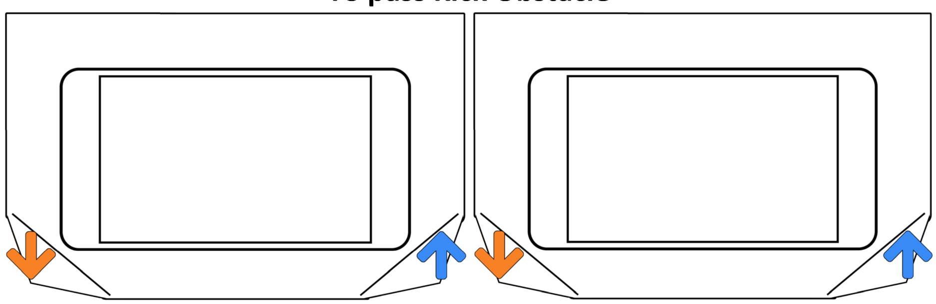
	Gesture-Training	Mapping-Training	No-Training
Session 1	95.00% Correct	95.00% Correct	92.50% Correct
Session 2	100% Correct	100% Correct	100% Correct

To pass Jump Obstacle



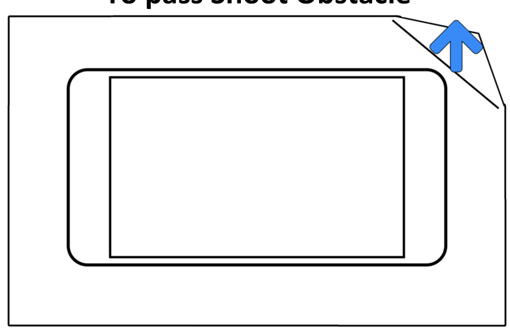
	Gesture-Training	Mapping-Training	No-Training
Session 1	97.5% Correct	95% Correct	83.75% Correct
Session 2	100% Correct	100% Correct	100% Correct

To pass Kick Obstacle



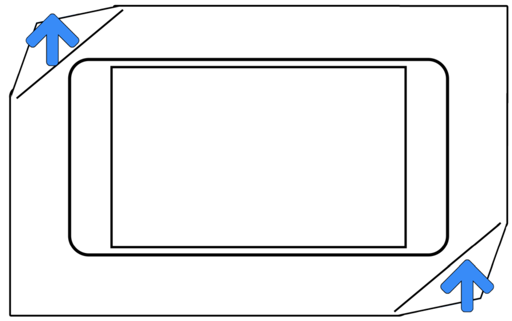
	Gesture-Training	Mapping-Training	No-Training
Session 1	80.00% Correct	80.00% Correct	85.00% Correct
Session 2	87.50% Correct	95.00% Correct	87.50% Correct

To pass Shoot Obstacle



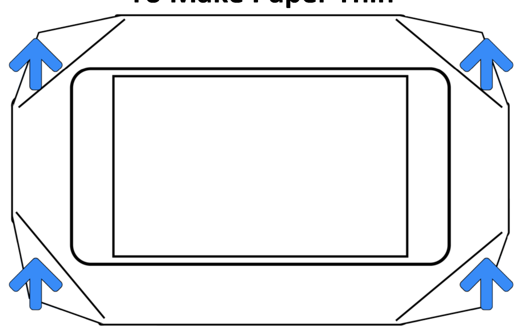
	Gesture-Training	Mapping-Training	No-Training
Session 1	93.75% Correct	95.00% Correct	85.00% Correct
Session 2	92.50% Correct	97.50% Correct	93.75% Correct

To pass Crumple Obstacle



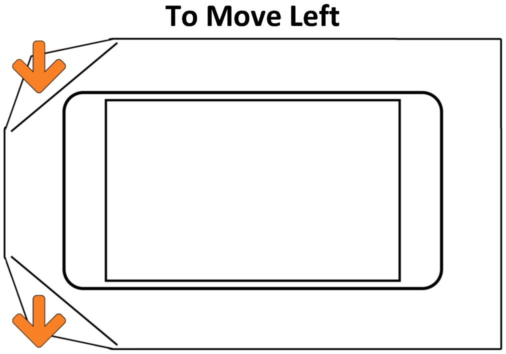
	Gesture-Training	Mapping-Training	No-Training
Session 1	88.75% Correct	90.00% Correct	86.25% Correct
Session 2	92.50% Correct	87.50% Correct	83.75% Correct

To Make Paper Thin



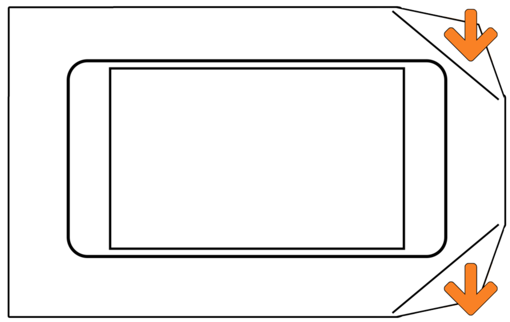
	Gesture-Training	Mapping-Training	No-Training
Session 1	85% Correct	97.5% Correct	96.25% Correct
Session 2	100% Correct	97.5% Correct	97.50% Correct

To Move Left



	Gesture-Training	Mapping-Training	No-Training
Session 1	91.25% Correct	100% Correct	90.00% Correct
Session 2	100% Correct	100% Correct	100% Correct

To pass Move Right



	Gesture-Training	Mapping-Training	No-Training
Session 1	91.25% Correct	100% Correct	90.00% Correct
Session 2	100% Correct	100% Correct	100% Correct

Appendix C
Consent Form

B.1.A Participant Consent Form Page 1 of 2

Carleton UNIVERSITY
Canada's Capital University

CUREB clearance #: 15-289

Consent Form

Title: Evaluating the Learnability and Memorability of Bend Gestures
Date of ethics clearance: 12/18/2015
Ethics Clearance for the Collection of Data Expires: 08/31/2016

This study involves the use of flexible displays and performing bend gestures. Flexible displays allow for new and novel forms of input other than the well known touch gestures such as swiping and tapping on a solid display. The aim of this study is to examine how well people can learn bend gestures and determine which teaching method yields the best retention. A bend gesture is when you perform bends on a flexible display to perform a command or an action.

This study involves two sessions which will take up to 60-minutes each and will be one week apart. With your consent, the sessions will be video-recorded for analysis.

At the end of each session, all participants will be asked to complete an online questionnaire giving their opinion and perception of how they felt the learning experience of using the flexible display was. There are no risks in doing this.

Participants must be at least 18 years old, comfortable bending and twisting an object and comfortable in the English language. Excluded will be those who have difficulty with motor skills and are unable to perform hand and finger movements. Participants cannot have used a bendable device before.

As a participant in this study, you will learn about flexible display devices and how they can be used to manipulate regular applications you use on a handheld device.

You have the right to end your participation in the study. You can withdraw at any time before the start of the experiment or up to one month after the research is complete by contacting the researcher and all your information will be immediately destroyed.

You will receive a $10 cash as compensation for your time at the end of the second session. This is yours to keep, even if you withdraw from the study.

This research is funded by NSERC - Discovery Grant.

Research data will only be accessible by the researcher and the research supervisor. Data will be stored electronically on Google Drive with password protection. None of your personal information will be accessed. Data collected during your session will be associated with a number that has no connection with

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B.1.B Participant Consent Form Page 2 of 2

CUREB clearance #: 15-289

any personally identifiable data.

Once the project is completed, all research data will be kept for five years and potentially used for other research projects on this same topic. The research data will also be used in presentations such as the Lead Researcher's Thesis Defence and their publications. At the end of five years, all research data will be securely destroyed.

If you would like a copy of the finished research project, you are invited to contact the researcher to request an electronic copy which will be provided to you.

The ethics protocol for this project was reviewed by the Carleton University Research Ethics Board, which provided clearance to carry out the research. Should you have questions or concerns related to your involvement in this research, please contact:

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Dr. Shelley Brown, Chair
Carleton University Research Ethics Board-B
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I ____, volunteer to participate in a study on evaluating the learnability and memorability of bend gestures.

_________________________ Signature of participant   _______________ Date

________________________ Signature of researcher   _______________ Date

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Appendix D
Learnability Metrics

Table 3: Categories of learnability metrics (Grossman et al., 2009).

Task Metrics: Metrics based on task performance T1. Percentage of users who complete a task optimally. T2. Percentage of users who complete a task without any help. T3. Ability to complete task optimally after certain time frame. T4. Decrease in task errors made over certain time interval. T5. Time until user completes a certain task successfully. T6. Time until user completes a set of tasks within a time frame. T7. Quality of work performed during a task, as scored by judges.
Command Metrics: Metrics based on command usage C1. Success rate of commands after being trained. C2. Increase in commands used over certain time interval. C3. Increase in complexity of commands over time interval. C4. Percent of commands known to user. C5. Percent of commands used by user.
Mental Metrics: Metrics based on cognitive processes M1. Decrease in average think times over certain time interval. M2. Alpha vs. beta waves in EEG patterns during usage. M3. Change in chunk size over time. M4. Mental Model questionnaire pretest and post test results.
Subjective Metrics: Metrics based on user feedback S1. Number of learnability related user comments. S2. Learnability questionnaire responses. S3. Twenty-six Likert statements.
Documentation Metrics: Metrics based on documentation usage D1. Decrease in help commands used over certain time interval. D2. Time taken to review documentation until starting a task. D3. Time to complete a task after reviewing documentation.
Usability Metrics: Metrics based on change in usability U1. Comparing “quality of use” over time. U2. Comparing “usability” for novice and expert users.
Rule Metrics: Metrics based on specific rules R1. Number of rules required to describe the system.

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