Augmenting Children's Tablet-Based Reading Experiences with Variable Friction Haptic Feedback

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ABSTRACT
This paper explores the integration of tactile feedback into children's electronic books (e-books) through variable friction surface haptics enabled by the TPaD Tablet technology. Through a user study with 10 pairs of children and their parents, we examine how children and parents conceive of and add haptics to a popular e-book. We report conceptual and practical differences in the ways in which children of various ages (3-8 years old) and adults envision haptic feedback within an e-book and conclude with a discussion of design considerations for creating haptic e-books.

ACM Classification Keywords
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces - Interaction styles.

Author Keywords
Surface haptics, e-book, reading, children, parents.

1. INTRODUCTION
Electronic books (e-books) are becoming a popular media for children, and approximately 23% of 0- to 8-year-olds report reading them [12]. E-books are thought to increase motivation and reading engagement [5]. While many e-books simply replicate the content of traditional paperback storybooks in digital form, a growing trend is to augment the e-book with interactive sounds and animations – also called enhanced e-books. Beyond sound, animation, and embedded games in e-books, other dimensions of interactivity that exist in physical books (e.g., textured materials) have been relatively unexplored [1]. Related efforts examine the ways in which tangible interfaces enhance learning (e.g., [9]) and the importance of multi-sensory learning opportunities that engage the physical body [15]. Haptic feedback provides another avenue for studying the affordances of blending digital and physical media and the immersive nature of such experiences.

This paper examines the use of variable friction surface haptics enabled by a novel interactive system called the TPaD Tablet [16]. Different from vibration or vibrotactile feedback, surface haptic technology varies the coefficient of friction as the user's fingertip moves across the display, giving the sensation of bumps and textures on a flat glass surface. Prior work has shown benefits of surface haptics for improving usability [8] and supporting communication [10]. However, little is known about how haptic feedback should be designed for children. To better understand this, we developed an application for the TPaD Tablet, in which children and parents are able to author haptic e-books. We then used this application to examine how parents and children individually add haptic feedback to a popular children's e-book, revealing their practical and conceptual intuitions for the design of this novel experience.

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2. RELATED WORK
Recent work has begun to examine child interaction with e-books. One study using researcher-created, developmentally-appropriate e-book content has found that e-books can have a positive effect on children's comprehension [13]. However, work that compares commercially-available e-books to traditional paper books indicates that children perform equally well on measures of comprehension, but children and parents engage with the books differently depending on whether it is paper or electronic [7]. In other work, Colombo and Landoni [3] suggest that mediated reading experiences must overcome book dematerialization (i.e., loss of tangible feeling of a physical book). Haptic e-books may be able to help overcome this and potentially provide a more immersive and engaging reading experience. Prior work has also examined co-design of e-books with children, analyzing children's perspectives on how they would improve the interface and experience of e-books [4]. In this work, children played an active role as designers of new interactive experiences, and our work also involves children directly as creators of new interactive content. Indeed, enriched e-books can have a positive effect on children's reading experiences [5], and this work suggests that children's e-reading experiences may greatly benefit from interactive and multimedia enhancements. Beyond sound and animated enhancements, haptic feedback is another way to enrich basic e-books. However, we have a limited understanding of how to design or integrate such enhancements to an e-reading experience.

While considerable research has focused on improving the e-reading experience for children, the concept of haptic e-books has been relatively unexplored. Alam and colleagues [1] developed a haptic jacket, armband, and sofa to augment an e-book reading experience with vibration feedback. An evaluation of this system showed initial positive effects of haptic feedback on short-term recall of storybook content with tweens and teenagers (ages 12-18) [1]. Relatedly, research examining physical tactile letters and paper books with manipulatives (e.g., with lift-the-flap, moving tabs, and textures) provides further insights into this design space.

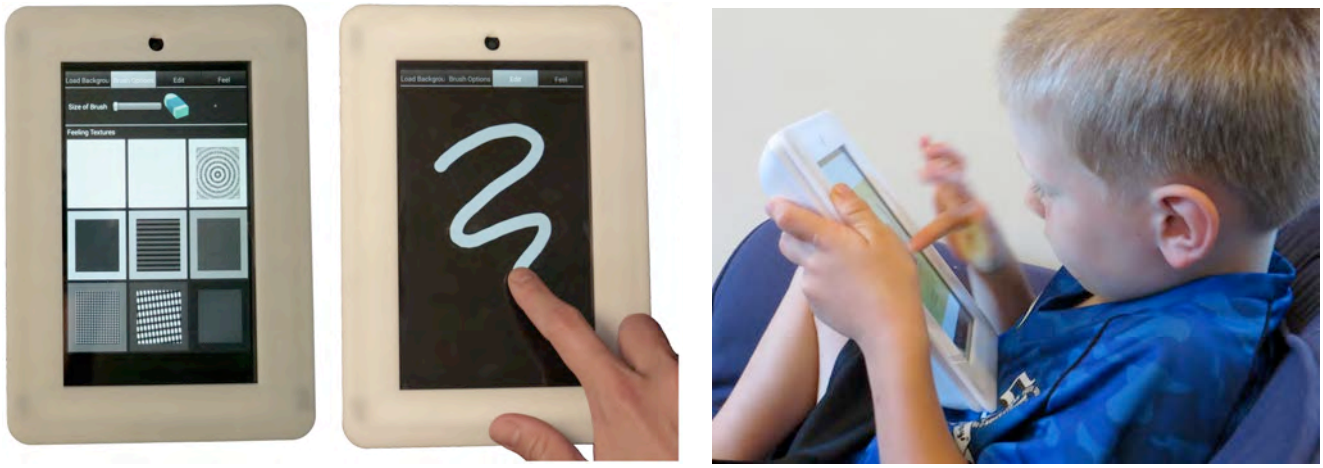

Figure 1: *Left*: Texture palette in e-book authoring application, users "paint" haptic patterns onto pages of an e-book, with black areas assigned high friction and white areas low friction. *Right*: Child (age 4) feels haptic textures on e-book pages.

For example, Bara *et al* [2] found that pre-reading kindergarten children were better able to decode words and recognize letters after interacting with tactile letters compared to children interacting with printed letters. A number of factors may affect the haptic experience for younger children, such as their conceptual understanding of haptic feedback, the appeal of haptic technology, and the ways in which haptics are integrated into e-book content.

3. HAPTIC E-BOOK APPLICATION

To study the concept of haptic e-books in more detail, we iteratively developed an application for the TPaD Tablet [15]. This particular version of the TPaD incorporates a first generation Google Nexus 7™ tablet, a glass sheet with piezoelectric actuators, a microcontroller circuit, and a lithium polymer battery. The TPaD surface generates haptic feedback by dynamically changing the friction of the glass surface through high frequency (~35 kHz) and low amplitude (~1 µm) out-of-plane oscillating motion. This oscillating amplitude has an inverse effect on the friction coefficient µ. That is, varying this oscillation modulates from low friction (full oscillation) to high friction (no oscillation). The TPaD provides friction feedback by sensing finger position at a frequency of 60 Hz. This friction modulation is different from tactile feedback through vibration actuation (e.g., cellphone vibration). The variable friction of the TPaD actively applies forces to the finger causing the skin to stretch while also creating vibration by oscillating amplitude, enabling a wide vocabulary of textures that are rendered directly onto the flat glass tablet display.

We created an Android application using the TPaD Tablet SDK to enable exploration of the concept of haptic e-books. Users import e-book pages from a collection of storybook images stored on the tablet device. Haptic textures can be added to the image by selecting a specific texture from a palette, "painting" the friction patterns directly onto the image, and then feeling the resulting haptic overlay. A palette of nine contrasting textures (See Fig. 1, left), represented with gray-scale images of the underlying haptic pattern, is available for users to add to storybook pages. Textures were selected based on prior work [8][10], feedback from experts in surface haptics, and iterative prototype testing with children and parents. The application provides a user-adjustable brush stroke and eraser for editing, and users can switch between an "edit" and "feel" mode to test out the haptic overlay.

4. METHOD

We conducted a laboratory study with ten parent-child dyads (N=20). Children were ages 3-8 and equal numbers male and female. Parent-child dyads were invited to the researchers' lab space, which was designed to feel like a family living room (e.g., couch, child-size tables). One adult participant had previously used a TPaD tablet. All ten children had experience using a tablet computer to play games, watch movies, read books, etc.

Researchers led the parent-child dyads through an initial training period to familiarize them with the TPaD and the sensation of touching the display. Then parents and children individually used a TPaD with the e-book authoring application to indicate how, where, and which haptics they would apply to a predetermined set of storybook pages. While the technique of Cooperative Inquiry [6] is useful for engaging children and parents in the design process, here we purposefully separate children and parents' responses to assess their intuitions about the design of e-books. We do this to understand whether there are *conceptual* and/or *practical* differences in how children and parents conceive of haptics within the context of an e-book. To maintain scope and enable systematic analysis across a focus set of content, we selected six pages from a popular e-book, entitled "Clifford Helps Out" (recommended for grades pre-K-3 or age 4-9). After this, researchers conducted a brief interview with the dyad to understand the authoring experience.

All testing sessions were video recorded and transcribed. When possible, we quantified user behaviors based on video data, transcripts, and device log file data. For the qualitative analysis, multiple researchers reviewed the video data and transcripts to identify preliminary codes, iterating between open and axial coding, and then derived the themes presented below [14].

5. RESULTS

5.1 Selecting and Applying Textures

There were practical differences in the ways in which parents and children selected and applied textures to the e-book. On average, parents added textures to 3.00 (SE = .35) areas per page. Some were concerned about adding too many interactive regions to a page. Children added texture to roughly half the number of areas that parents did (M = 1.62, SE = .16), which is significantly less than parents (U = 3.25, p = .001). Only one participant (C5, age 8) purposefully left a page without haptics.

Throughout the authoring activity, participants referenced physical "touch-and-feel" books, and their knowledge of these books influenced the application of haptics. As with physical touch-and-feel books, both parents and children applied haptics to large, prominent areas within each page rather than smaller details within the illustration. P3 said, "I put things in large spaces because I felt like if you put things in tiny little spaces it would be less effective for a child... Too hard to identify…" On several pages there was agreement among parents and children about which particular objects should have texture, and these were typically the most prominent object on the page and also related to the story narrative (e.g., the dog's body as a girl pets him; a large ball when dog plays). Overwhelmingly, the focus of haptics was on objects in the book. We anticipated that participants would add haptics to the text, but only two participants (both parents) mentioned applying texture to words. P1 said, "So if it was about Clifford eating, I highlighted the word eat and the tongue and the mouth so then they (children) would be drawn to that and help give another clue as far as decoding the text."

5.2 Age-Related Conceptual Differences

In agreement with prior work [10], participants applied haptics to convey literal texture, action, and emotional information. However, we observed differences in terms of how parents and children conceived of haptics along these dimensions.

As somewhat expected, younger children (ages 3-5, preschoolers) chose textures based on liking the feeling or look of the texture. C2 (age 4) said, "I wanted them, then I feeled it, and then it was awesome." C7 (age 4) said, "I like the way it looks," noting a strategy of selecting based on the visual quality of the texture palette rather than the tactile feeling. Younger children were less likely to articulate the relationship between the feeling on the tablet and the feeling of an object in the real world, indicating that appropriate scaffolding (e.g., through parent dialog or audio/visual cues) will be needed to support their emerging conceptual understandings of haptic feedback. There was only one instance of a younger child (C10, age 4) selecting a pattern based on literal texture. When asked why she selected a particular texture for the cat, she said, "Because the cat needs to be soft."

Older children (ages 6-8, grades K-2), in contrast, clearly articulated reasons for selecting textures based on the perceived mapping between literal texture and the available textures on the tablet, demonstrating logical reasoning characteristic of the concrete operational stage of development [11]. C1 (age 7) said, "I kind of know what they feel like in real life, and I'm feeling the textures and deciding which is the closest one to what it would feel like." C4 (age 7) explained, "I picked the one that I thought it would feel like." She continued, "The ball, I know what balls feel like, so I picked the one for the ball." C5 (age 8) noted that adding textures makes sense when it matches the texture in real life.

In contrast to children, adults articulated more diverse and complex ways in which haptic feedback could support an e-reading experience. Similar to children, adults suggested using haptics to convey literal texture, but they did so in rich and interesting ways. P4 said of one texture she applied to the dog, "It feels more like striations, rough like a dog's fur." A parent (P7) who added a texture to the dog's tongue justified this because it "feels kinda scruffy, kinda rough." Similarly, P4 explained, "His tongue, something spongy… it feels spongy to me." P7 added texture to a ball and said it "feels like the grip on a basketball." Parents selected textures that had different feelings depending on how the user moves across the display, particularly if this parallels interaction in real life. P3 said, "On his fur… one of these that feels different when going different directions… 'cause when you pet a dog different directions it feels differently." Parents analyzed the subtleties of the textures and how these features mapped to the illustration. P2 explained, "The cars and trucks should be something… this is smooth and some kind of metal, but smooth in a more substantial way… there's more to it, more grit."

Physical haptic books predominately use tactile regions to convey literal texture; however, in a digital context, parents perceived haptic feedback as useful for illustrating action related to the story narrative. P6 added haptics to where a tire meets the road because "it feels like some resistance, you get stuck a little" to convey the friction of the tire on the road. P8 added haptics in the same spot to show the car "screeching to a halt." P3 said, "That one still feels like the rumbling of a car," and then explained that cars should have a different texture depending on whether they are stationary or moving. Other examples include adding haptics around the dog's nose to indicate breathing and on motion lines in the illustration. Similar to conveying action, parents used haptics to indicate cause and effect related to the narrative. P1 said she would add haptics "in between the cat and the car…to highlight that…the car might hit the cat." Then she explained, "the most important thing is that they're going to run over [the cat]… put it on the road there," aiming to call attention to the cause and effect described in the narrative. Only one child (C8) mentioned using haptics for action when a character jumped. Finally, adults also added haptics to convey the emotions of characters in the story. P8 added haptics to characters observing a car crash. She said, "the one [person] who was having a bigger reaction, covering her eyes, I made her vibrate more. And the one who was looking a little distressed vibrated less." In this way, she matched the intensity of what they were feeling with the intensity of the haptics.

5.3 Adult Strategies for Adding Haptics

While children designed the haptic experience for themselves, often selecting textures based on personal preference, parents articulated strategies for design that they thought would help their children understand the book. Hence, adults' behaviors provide insights into how to design this new media. Our analysis revealed three common strategies among parents. First, parents made the haptic experience consistent between pages. Parents purposefully applied the same texture to the same objects across multiple pages (e.g., the dog's fur, cars, grass, and clothing had an assigned texture throughout the book). When exceptions to this were made, they were well justified. One parent (P8) noted that kids would notice if haptics were not applied consistently across similar objects. She said, "If you were reading this and both cans didn't vibrate, he (son) would be like 'how come this one vibrates and that one didn't?'" Second, parents focused on applying contrasting textures within each page. P1 said, "that one because I'd want it to be enough contrast between the taxi's texture and the dog's texture." P7 explained, "But I want something that feels different enough… I don't know that…you could put this and this together and have someone feel two different things." Helping children discriminate among multiple textures on a single page was important to parents. Third, parents applied haptics to highlight or call attention to objects, actions, or parts of the narrative. P1 explained, "The reason I would want it (texture) is to try and focus their attention on the main thing to help support the text…" She continued, "If I'm trying to use it to help my child focus on what they're reading… I would choose things that help them focus on

what they're supposed to be doing." Similarly, P7 said that she was "picturing the touch-and-feel books for kids, so I was trying to pick places I thought kids' eyes would go to..."

5.4 Feedback on Concept of Haptic E-Books

Children were generally positive about the concept of haptic e-books. For example, C9 (age 6) noted that the textures were "fun to feel." Two young children reported a heightened sensory experience and noted that haptics should not be on things one should not touch (e.g., fire). One child (age 4) called the tactile sensation "itchy". In terms of the e-reading experience, C1 (age 7) said that this "can help kids understand if they can't read the words." Several parents also thought the textures would augment the reading experience. For example, P2 said, "It helps convey information about the story to the reader. It makes it more real." The value of haptics in this context is "to act as a support for the text," said P1. P8 commented, "It would make the book more fun to have the textures..." and "more interactive and more playful…" P9 said it would be good for textures "not normally experienced" and that the important aspect is that it enables novel tactile sharing experiences. However, several parents noted the limitations of digital textures compared to textures in physical books. P7 said, "I don't think it replicates a fuzzy lion's tail or shiny butterfly."

6. DISCUSSION AND CONCLUSION

This study explores how children and parents conceive of and add haptics to a popular children's e-book. Our analysis suggests an initial set of considerations for the design of haptic e-books:

- *Limit the number of haptic regions on each page:* Apply haptic textures to 1-3 large or salient areas per page.
- *Make textures consistent:* Textures should be consistent across multiple pages of the book (e.g., characters have the same texture throughout), although applying a different texture can call attention to changes in the character (e.g., when in motion vs. stationary).
- *Make textures congruent:* If conveying literal texture, haptics should mimic the real world texture, including spatial patterns that afford directional movement (e.g., feeling of Clifford's fur depending on how the dog is positioned).
- *Use textures with contrasting intensities:* Use contrasting textures with stronger, more noticeable haptics to highlight more important features in a scene. Background elements may have no haptics or very subtle haptics.
- *Use haptics to supplement the narrative:* Haptics can enhance the story narrative by calling attention to characters or objects described in the text.
- *Use haptics to illustrate character actions or emotions*: Parents envisioned adding haptics as action or emotion, although children may need support in understanding this more abstract use of haptic feedback.

While this work is preliminary, it provides the first exploration of designing haptic e-books for children using variable friction surface haptics. As such, the present study is limited by examining only a single style of illustrations within a classic children's series; other illustration styles or realistic photographs may encourage adding haptics in alternative ways. It is also likely that the narrative structure and content will influence the appropriation of haptics. Another limitation of this early work is that the novelty of the haptic technology may have affected participant understanding of this concept and their approach to design, and repeat experience with this media form could lead to different design patterns. Nonetheless, this work provides a starting point for subsequent design of haptic feedback in the context of e-books for young children. We hope this preliminary work informs future studies of learning with haptic displays, where the immersive nature of haptics may potentially increase engagement and enhance children's learning of complex phenomena (e.g., [15]).

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