FeelSleeve: Haptic Feedback to Enhance Early Reading

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Figure 1. A child reading with FeelSleeve and feeling haptic effects associated with story events on her hands.

ABSTRACT
Engaging children with traditional approaches in education, especially reading, grows ever more difficult in the face of their attachment to tablets and computer games. We explore the possibility of making the story reading experience more interesting and memorable for children using haptic augmentation. In this paper, we present *FeelSleeve*, an interface that allows children to feel story events in their hands while they are reading on a mobile device. FeelSleeve uses transducers and audio output from the tablet within a gloved attachment to create vibratory effects that are meaningfully related to story content. We describe a study investigating whether embedding such haptic feedback into stories enhances reading for six to nine year olds. Our results indicate that story events accompanied by haptic feedback are better comprehended and appear to be more salient in memory. These results provide evidence that haptic effects have the potential to improve children's reading experience and make it more memorable.

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INTRODUCTION
As children transition from story listening to active reading, they undergo a fundamental and challenging transformation. Listening to stories sets the stage for reading by introducing children to a broad range of language, including new vocabulary and metaphorical extension, and establishing general skills of spelling and grammar [20]. Reading adds additional demands, not only in word decoding and oral language production, but in comprehension of ever more advanced language structure. To bridge the chasm from listening to reading, texts commonly introduce scaffolding in the form of alternative media, particularly illustrations. More recently, additional modalities and interactive media have been introduced even at the story listening stage [21, 24]. However, the integration of haptic feedback into the story listening and reading experience is not well explored. Furthermore, few controlled experiments investigate whether adding haptic feedback can enhance story reading for children by improving their comprehension and memory. The present research provides such an experiment

in the context of a mobile device. Relevant related work, discussed next, includes research relating haptic stimulation to language and memory and technologies that enable this approach.

RELATED HAPTIC TECHNOLOGY

Haptics and Language

Early efforts to show that language and meaning can be associated with haptic feedback were based on alphanumeric mapping, with limited success [9]. More recent work developed haptic phonemes, which can be combined to form haptic words [8], and a vocabulary of distinct haptic icons [29].

Still more recently, Israr and colleagues [14] integrated haptic feedback into a chair pad in order to convey the semantics associated with language phrases. They developed a haptic vocabulary for 23 *feel effects*—such as *rain*, *heartbeat*, and *creature walking*—that were created using spatially displaced, temporally interspersed pulses. Values for the actuators' parameters were based on a pair of studies in which, first, participants adjusted the intensity, duration, and inter-pulse interval of the actuators associated with a given phrase, and second, an independent group of participants validated the derived values [14]. The studies showed that feel effects led to reliable language/haptic associations, that synonym phrases could be substituted for the original language phrases, and that new effects could be constructed by inference.

There have also been some attempts to integrate haptic feedback into story listening. One such attempt was Sensory Fiction [11], where adults wore a vest that allowed them to feel artificial heartbeats that changed with the mood of the story. Changes in the temperature and pressure in the vest could also reflect story events. Another attempt involved a haptic vest to enrich children's story listening experience [32]. A study was conducted to test four to six year olds' ability to associate haptic effects with semantic interpretations. The results found that five and six year olds tended to assign lower agreement to incongruent versus congruent pairings of haptic effects and meanings, indicating effective communication of meaning by the haptic signal. The study further demonstrated that congruent haptic-meaning pairs could improve story comprehension and memory for that age group.

Reading with Other Modalities

Thus far we have reviewed research that attempts to use haptic effects to signal meaningful content. As our goal is to facilitate the incorporation of haptic feedback into the story reading experience, it is important to consider efforts of others to engage the young reader with nonverbal input, including haptic effects.

The use of nonverbal augmentation for children's reading is longstanding, of course. Typical children's books include visual illustrations along with text to convey information and meaning. Illustrations have been shown to enhance memory for story content, while also directly facilitating comprehension [21].

Some tangible interfaces have also been created to accompany storytelling and reading. Tanenbaum et al. created The Reading Glove, which allows users to extract memories, presented in the form of recorded audio, from ten objects by using natural grasping and holding behaviors [28]. The tangible, augmented-reality Magic Story Cube went further, integrating multiple modalities, including speech, 3D audio, 3D graphics and touch, in order to provide children with multi-sensory experiences in the process of storytelling [33]. Similar approaches combining tangible interfaces with storytelling include StoryMat [25] and ListenReader [2].

Effect of Haptics on Memory and Learning

The idea of using haptics to anchor memory and comprehension during reading is also supported by research in other contexts. Yannier et al., for example, found that students remember the cause-and-effect relationships in climate and geography better when presented with haptic feedback [31]. Research on embodiment has shown that memory for actions (e.g. performing a command such as "open the book") can be superior to memory for the verbal description of commands, suggesting that memory encompasses embodied information [7]. Haptic feedback has also been used to teach people who are visually impaired or dyslexic [15]. Jones et al. demonstrated that the use of a force-feedback device tended to support the development of 3-dimensional understanding of objects [15]. Together, these studies suggest that haptic feedback may also have the potential to enhance the reading experience.

Haptics and Mobile Devices

To take advantage of the current affinity for mobile devices, our aim is not only to integrate haptic effects into children's reading, but also to do so by means of the technology that they widely use. Thus research related to haptics on mobile devices outside the context of reading is also relevant.

A common use of haptics on mobile devices is to inform the user about incoming calls and messages. Early systems used a single unbalanced mass linear resonator, but more recent research has replaced the resonator with a speaker-like tactor, presenting tactile content that varies in both frequency and amplitude [5, 22]. In another approach, Yang et al. developed cues for hand-held devices via a system of 12 vibrotactile panels, each comprising a linear resonant actuator, a covering surface, and a vibration isolator [30]. Luk et al. also presented a handheld tactile display prototype to integrate haptics into mobile interaction, but used piezoelectric pins that stretch the skin laterally [19].

Other approaches have focused on creating illusory haptic sensations in order to increase resolution on the device. Such illusions work by introducing virtual actuators between real vibration sources. Seo and Cho, for example, demonstrated that vibrotactile flow could be reliably produced on a mobile device using phantom sensations in which spatially separated vibrotactile actuators stimulate different skin zones to induce a single tactile sensation midway between two stimulation points [26]. Lee and colleagues have also demonstrated use of a wide range of illusory percepts on handheld controllers, toys and mobile devices [17].

More recently, friction-based tactile technologies have been introduced to the touch screens of mobile devices [3, 18]. The level of friction is yoked to the location of the finger relative to the content on the screen.

Most of these technologies have focused on integrating haptic feedback into the screen of a mobile device or on vibrating or changing the friction of the device as a whole. In contrast, our FeelSleeve approach creates haptic sensations that are transmitted to the hands of a user who is simply holding the tablet in a natural position. This design, described in detail below, means that the reading experience does not need to be interrupted by an additional intentional action to trigger the haptic effect.

THE FEELSLEEVE STUDY

To help explore the question of whether haptics can improve children's reading experience, we created and tested a tablet-based FeelSleeve, a device that wraps around a handheld surface like a protective cover and provides localized vibrotactile stimulations on the hands. We programmed the FeelSleeve to coordinate with the display of text elements in our stories in order to produce feel effects (FEs): haptic patterns that, by virtue of their co-occurrence with a linguistic phrase, generate dynamic and expressive effects on the user's body [14]. In the study described below, we test whether the ability to feel events like rainfall, tapping, and heartbeats while reading about them can enhance memory for and comprehension of the story.

Experimental Method

Participants

Forty-four children from six to nine years old participated in our study. There were 16, 14, and 14 from First Grade to Third Grade, respectively.[1] Children were recruited from a participant pool and by giving out flyers. We excluded children who were reported as non-readers. The Institutional Review Board approved the recruitment methods.

Apparatus: Hardware

The FeelSleeve hardware used to deliver feel effects on the tablet during reading is shown in Figure 2. The device consists of a 3D-printed, soft cover sleeve embedded with two vibrotactile exciters (Tectonic Elements Ltd., model: TEAX19C01-8, Cambridgeshire, UK) and a simple electronic driver. The exciters are spaced 180 mm apart and enclosed in compartments in the sleeve. The moving ring of the exciter is pressed against the vibrating flap placed on the back of the sleeve so as to optimize the vibratory response of the embedded exciter and keep the stimulations localized and distortion free. When a user holds the FeelSleeve, it directly stimulates the skin of the hands. The exciters are driven by a custom electronic driver to amplify the stereo audio output of the tablet using two 1-Watt audio amplifiers (model LM4889, ti.com). The driver is powered either by a wall adapter or by a 6 V battery, and a switch is provided to turn the driver on and off. Fig 2(b) shows the location of exciters, vibrating flaps and the electronic driver.

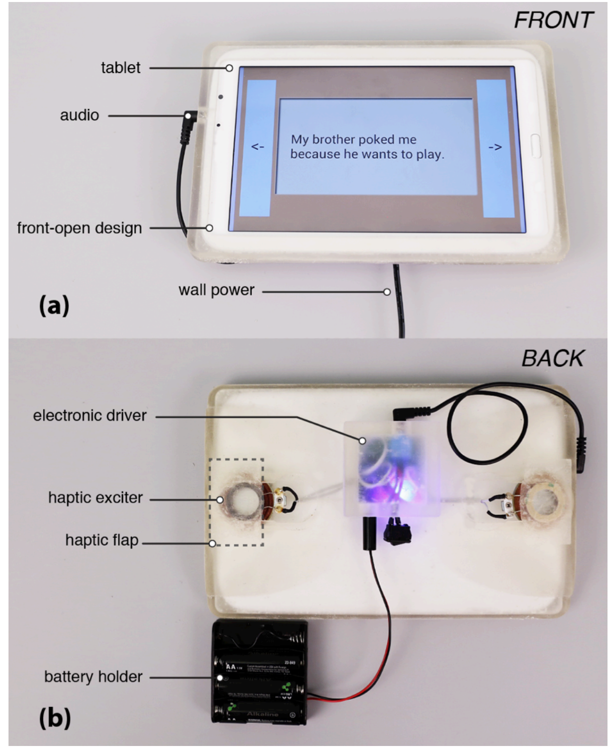

Figure 2. FeelSleeve hardware.

Our design objective was to create a tablet enclosure that could house two haptic transducers for stimulating the hands while allowing the user to interact with the tablet in a natural, comfortable way. The semi-flexible, cover-shaped sleeve with a minimal lip and open front holds the tablet securely, allows it to be inserted and removed easily, and leaves most of the screen surface available. Compartments holding the transducers and channels for wiring are unexposed once the sleeve is attached.

The two flaps pressed by their exciters are the haptic elements of the FeelSleeve that relay vibration from the exciters to the user's hands. The thickness, size and surface finish of the flaps are designed to achieve localized, smooth and noise- and distortion-free haptic stimulations. The thickness of the flap has a significant effect on its vibratory response. A thick flap dampens response, resulting in high

[1] We did not go beyond Grade 3 because pilot testing with 4th graders indicated that they performed at ceiling level.

power requirements, while too thin a flap wears down quickly, eventually delivering unreliable and uncomfortable stimulations. The prototype uses a safe thickness of 1.5 mm. The surface area of the flap is 50 mm x 30 mm with a 2 mm void layer directly below the flap. The void layer allows the flap to move freely in the open space, reduces stretch between the flap and sleeve, and amplifies vibratory response of the flap. Finally, a pilot evaluation of four users contrasting texture versus smooth flaps found that all participants preferred the smooth flap to the textured flap, which was found uncomfortable and distracting. Therefore the prototype uses flat flaps, as shown in the bottom of Figure 2.

FeelSleeve's flexible cover is made of a light and relatively soft rubber-like material (TangoPlus FLX930, www.stratasys.com, Shore hardness: scale A, 26-28), so that it is comfortable for users to hold over long durations. Correct placement of the hands with respect to the actuators is ensured in two ways. First, the short ends of the sleeve have protrusions that, when grasped, provide consistent contact between the hands and the vibrating flaps while leaving the thumbs available for navigation (Figure 3). Second, small pockets (in the shape of gloves) are attached to the back of the sleeve to guide users' hands to the right location to feel the haptic patterns (Figure 1). In order to make FeelSleeve visually appealing for children, we painted the sleeve and the gloves attractive colors. The weight of the sleeve is 400 g; combined with the tablet, the full weight is less than 750 g, typical of other sleeved devices.

Stimuli: The Language Component

Our stimuli are co-temporal linguistic/haptic pairings known as feel effects, or FEs. The linguistic component of each FE occurs in the context of one of two stories written in the first person by a professional storywriter for children.

The stories had different content but similar story arcs and were matched for word count. The protagonist of one story (*Space*) was a child pilot who delivers "Very Important Packages" and is headed to Jupiter on his or her birthday. After going through a meteor shower, the child arrives on Jupiter to deliver a package; once there, s/he walks into a surprise birthday party and discovers that the package contains the cake. In the second story (*Jungle*), a child jungle explorer searches for a silver-striped tiger, which, according to legends, is as big as a building and very scary. After hiking through the jungle and having adventures with other animals along the way, the explorer finds the silver-striped tiger, which turns out to be as small as a squirrel and very friendly.

Figure 3. The back of FeelSleeve highlighting functional and ergonomic design.

For purposes of tablet presentation, the stories were divided into *frames*: segments of one to four sentences that fit on a single screen. Each frame consisted of a maximum of 25 words (average: 16 words). The original versions of *Jungle* and *Space* were written for story listening, where the need to decode the text is not a factor [32]. Accordingly, we adjusted the original text for reading level using lexile-to-grade correspondences[2] to affirm that the reading difficulty of each segment was appropriate for the target age group of six to nine year olds. In their entireties, *Jungle* and *Space* had lexile scores of 480 and 420, respectively.

Each story contained twenty frames, ten of which were paired with appropriate haptic input to create the feel effects. Sample frames from each story and the name of the associated FE are shown in Table 1; the haptic components of the FEs are described in the next section.

Text in Frame	Associated FE
As a brave explorer, I love walking in the jungle, even when it's raining. Rain won't stop me!	Rain
I'm glad it stopped raining. But now my boots make a *squish-squish* with each step in the mud.	Squish Squish
Yipes! What's that? "Oh, Hammy! Get out of my space gloves silly!" My pet hamster loves to sleep in there.	Creature Walk
I start the engines, and they hum to life. 3…2…1… Blastoff!	Purr
But why is it so dark in here? My heart starts racing. Then suddenly I hear: SURPRISE!	Heartbeat
I feel a tap and look up to see my mom standing there.	Tap

Table 1. Feel Effects associated with the story text displayed on the screen.

[2] https://lexile.com/analyzer/

Space	Jungle
Ring *(Set 1 and 2)*	Rain *(Set 1 and 2)*
Creature Walk *(Set 1 and 2)*	Roar *(Set 1 and 2)*
Push *(Set 1)*	Poke *(Set 1)*
Purr *(Set 2)*	Creature Walk *(Set 2)*
Shake *(Set 1)*	Tap *(Set 1)*
Poke *(Set 2)*	Squish squish *(Set 2)*
Slap *(Set 1)*	Heartbeat *(Set 1)*
Rain *(Set 2)*	Shake *(Set 2)*
Heartbeat *(Set 1)*	Swipe *(Set 1)*
Tap *(Set 2)*	Purr *(Set 2)*

Table 2. FEs for *Jungle* and *Space* stories in sequence; participants felt either Set 1 or Set 2 effects, with counterbalanced story order across all users.

Table 2 shows how the full set of FEs were actually used in the study. The first two FEs in each story were always active (i.e., had the haptics played while the text was visible) in order to familiarize the child with the sensations and avoid simple effects of surprise or novelty. The remaining eight FEs were split so that those that were active in one condition were inactive (text shown without haptics) in the other; the within-subject comparison avoids conflation from reading variability. Active and inactive FEs alternated to maintain approximately equal spacing. Each child was randomly assigned to one of four conditions, which differed with respect to story order and which set of FEs was active.

Stimuli: The Haptic Component

The haptic component of a FE realizes the semantics of a story event using a composition of four parameter settings for each of the two tactors in the FeelSleeve: SOA (stimulus onset asynchrony), duration, ramp-up rate, and intensity. In order to increase the spatial resolution of the haptics, we employ parametric models of sensory illusions in our rendering schemes to create the perception of multiple points, moving points, hopping and modulating points, bumps, knocks, taps, etc.

More specifically, to expand on the intrinsic effects made possible by the resident transducers, we implement three common illusions on the skin: apparent tactile motion [16; 27], phantom tactile sensations [4, 1] and sensory saltation [10]. These illusions are well investigated in previous research and have been shown to reliably create illusory effects on the skin of the back [12, 13], hands [17, 26], arms and torso [6] and other parts of the body. The use of these illusions in the context of the FEs in our stories is illustrated in Figure 4.

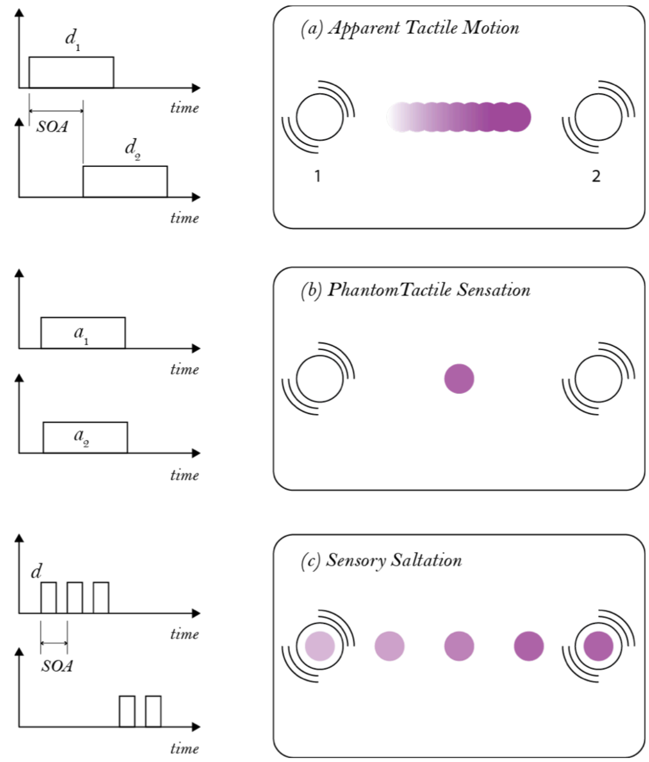

Figure 4. Sensory Illusions used for high-definition haptic rendering on FeelSleeve.

Although some new FEs were created specifically for this study, most of the FEs we used were adopted from a library tested in a previous study on adult participants [14], adapted for two actuators. The original forms of the adapted FEs had also been tested on children and shown to be effective for children of five years and older [32]. We organize FEs with related semantic meanings and haptic realizations into families. The families used in this study are:

- ***Rain*** (both stories): produced by random stimulation of ten vibratory points (two real and eight phantom sensations created as in Figure 4(b)). Duration defines size, intensity defines strength and SOA defines the frequency of drops.
- ***Heartbeat*** (both stories): produced by activating both transducers simultaneously for two pulses. SOA between pulses defines heart rate.
- ***Swipe*** **and** ***Squish squish*** (*Jungle*): produced using continuous apparent movement (see Figure 4(a)) from one transducer to another. In particular, *swipe* uses apparent movement from the left actuator to the right actuator, while *squish squish* uses two swipe motions in a row from right to left. Control parameters are SOA (speed), duration (continuity), intensity (size), direction and number of occurrences.
- ***Creature Walk*** (both stories): produced using five vibratory points moving from one transducer to another (see Figure 4(c)). Control parameters are intensity (size

of animal) and SOA (speed). The approach was used to create both the *lizard running* effect in *Jungle*, and the *hamster walking* effect in *Space*.

- ***Purr* and *Roar*** (both stories): produced by playing a purring sound through both transducers, with intensity (loudness) and tempo (rhythm) adjusted for use. *Tiger purring* in *Jungle* and *engine rumbling* in *Space* were created with this method.
- ***Tap* and *Shake*** (both stories): produced by activating both transducers simultaneously in pulses. Control parameters are intensity (strength), SOA (urgency), duration (size) and number of pulses. Used for *hands shaking* and *seeds tapping* in *Jungle* and *body shaking* and *mom tapping* in *Space*.
- ***Push*, *Poke* and *Slap*** (both stories): produced by activating both transducers simultaneously one time. Intensity (strength) and duration (size) are adjusted. Used for *branch poking* in *Jungle*, and *slapping a button, pushing a door* and *knob poking* in *Space.*
- ***Ring*** (*Space*): produced by playing a ring tone through both transducers simultaneously. Controls are intensity and pitch.

The haptic effects were created using an open-source dataflow programming language, Pure Data (aka Pd, puredata.info), and stored as stereo (dual) channel wav files. The FE stimuli were created by compiling the stories in an Android application that displays frame-by-frame sections on the tablet screen as it plays back associated wav files via the FeelSleeve. The haptics are played in a loop for the duration in which the frame is displayed on the screen, so that users can experience the FEs again if they miss them the first time. Navigation to a different frame is under the child's control via two big buttons on either side of the text which respond to a thumb tap while the rest of the hand remains correctly positioned by the gloves (see Figure 1).

Test materials
Twelve post-reading questions with three alternative responses were constructed for each story. One question was directly related to each of the 10 frames with FEs (whether active or inactive). Two additional questions were included to test children's understanding of the gist of the story, one querying content and the other asking for a best title, where the correct response was intended to capture the overall theme.

Each question was presented visually and read aloud, initially without multiple-choice alternatives. Spontaneous answers were recorded and scored as correct only if the child reported the specific content related to the associated FE, thus constituting a test of the saliency of the haptically-signaled event. After the spontaneous response, the child was given three answers to choose from as a more general test of comprehension and memory. Some example questions are presented in Table 3.

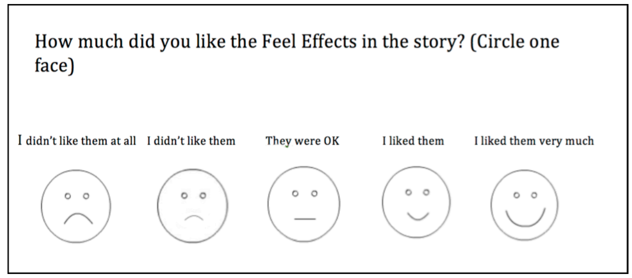

Figure 5. Post-reading question assessing FE enjoyment.

Procedure
The experimenter described the task to the child as reading text out loud on a screen while possibly feeling sensations on the hands. The child was shown that he or she could control the screen's forward (or if necessary, backward) advance with on-screen arrows. The child then put his or her hands into the FeelSleeve's gloves and was given two sample screens with active FEs. When the experimenter confirmed that the haptic pattern could be sensed, the experiment proper began. Children were told to read the sentences they saw on the screen out loud, pressing the arrow button on the right to go to the next screen when they were finished reading. They were informed that if they did not know how to read a word or what it meant they could ask for help, at which point the experimenter intervened with oral assistance.

After reading the first story, the child was asked to summarize it as a check on general attention. After summarization, questions were presented on paper and read aloud in two parts: the question alone, then the question with three alternative responses.

For most children the same procedure was repeated for the second story. Three children who were very poor readers were thanked and dismissed at this point.

What did the tiger do when it came up to you? a) It sat on my lap. b) It got into my jacket. c) It lay at my feet. (associated with *Jungle* FE: tiger purring in jacket)
How did you know your mom was there? a) She called my name. b) She tapped me. c) She kissed my hair. (associated with *Space* FE: mother tapping on child's hand)
Why were you surprised when you saw the tiger? a) Because it was small. b) Because it was silver and green. c) Because it was scary. (question about the gist of *Jungle*)

Table 3. Example comprehension questions.

After the second story, children were shown a five-point visual scale and asked how much they liked the FEs (see Figure 5) and whether they would prefer another story with or without them. Finally they were asked to report their favorite FEs and give general comments.

RESULTS

Comprehension Questions

Our primary analysis is based on the eight comprehension questions that corresponded to the FEs distinguishing Set 1 and Set 2. FE active (FE) and inactive (NoFE) scores were computed separately for each child as the percentage of correct responses for the four relevant questions in the condition. Figure 6 shows means for each story as a function of FE status.

An ANOVA was conducted for the multiple-choice results for the comprehension questions using within-participant factors of FE status (active, inactive) and Story (*Jungle*, *Space*), and the between-participant factor of Grade level. The analysis showed an effect of Story, $F(1, 37) = 36.62$, $p<0.001$. No other effects were significant. However, examination of the data by story indicated that children were essentially at ceiling when given the multiple-choice questions for *Jungle*. This pattern is consistent with previous research using a listening comprehension version of these stories with younger children, which found that *Space* produced lower comprehension scores [32].

Accordingly, we analyzed for FE and Grade effects in each story separately, using a two-factor ANOVA. For *Jungle*, no effects were significant. For *Space*, the effect of FE status was significant, $F(1,40) = 4.31$, $p = 0.04$, as was the effect of Grade level, $F(2,40) = 5.08$, $p = 0.01$ (Figure 7). The mean of the FE questions answered correctly was 2.72 out of 4 questions (68.2% with a standard error of 3.8%) while the mean for the NoFE questions was 2.32 out of 4 questions (58.3% with a standard error of 3.9%). Thus, across all grades, addition of an FE improved comprehension relative to the NoFE baseline by 17%.

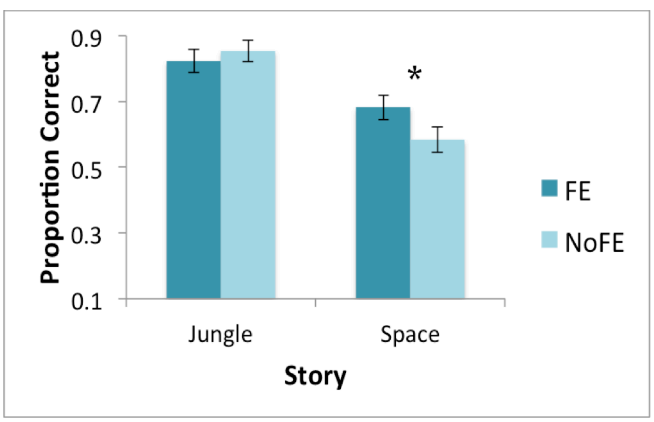

Figure 6. Proportion correct for comprehension questions by Story and FE status. Error bars are 1 standard error.

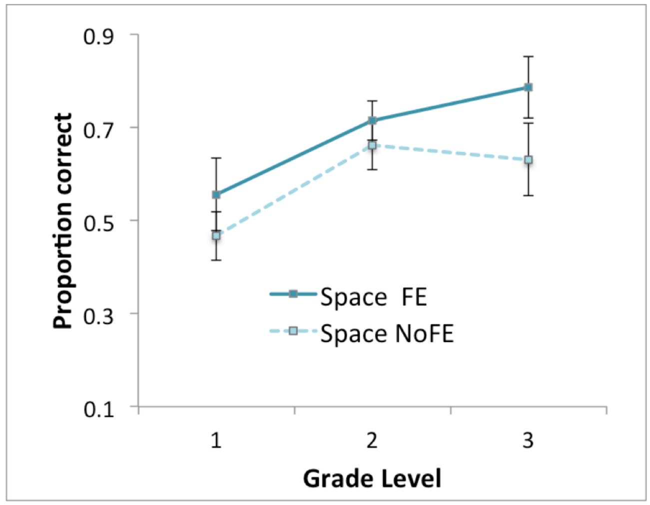

Figure 7. Proportion correct for *Space* comprehension questions by FE status and Grade. Error bars are 1 standard error.

Recall that gist questions were designed to check whether children understood the main idea of the story. An analysis of the multiple-choice responses for the gist content question indicated understanding was high, with 90% of children who read both stories responding correctly to *Jungle* and 95% to *Space*. The corresponding values for choice of the most thematic title question were 60% and 55%. All are significantly greater than chance ($p<0.01$).

Recall of FE events

We also analyzed the spontaneous answers to each question to see if, without seeing alternatives, children would recall the events related to the FEs. Because we were interested in assessing the saliency in memory for the specific event associated with an FE, a spontaneous reply was given credit in this analysis only if it mentioned that event, regardless of whether other details were correctly reported. For example, in response to the question about what the tiger did when it came up to the explorer, "it got in my jacket" would be a credited response because it referred to the FE event (tiger purring inside my jacket), but "it looked right at me," while correct, would not be credited. Figure 8 shows the mean proportion credited by story and FE status.

An ANOVA was conducted using within-participant factors of FE status (active, inactive) and Story, and the between-participant factor of Grade level. This analysis (which excludes four children who completed only one story) showed a significant effect of Story, $F(1,37)=15.50$, $p<0.001$. The effect of FE status was marginal, $F(1,37) = 3.36$, $p = 0.08$. No other effects approached significance.

Given the obvious difference between story performance levels, also evident in the comprehension measure, we analyzed each story separately, using a two-factor ANOVA with FE status as a within factor and Grade as between. The effect of FE status was significant only for *Space*, $F(1,40) = 4.60$, $p = 0.04$. For this story, the mean of the FE-related

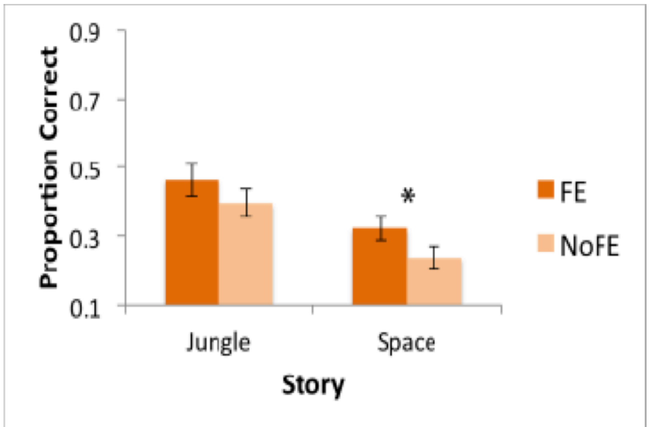

Figure 8. Score for Recall of FE events by story and FE status. Error bars are 1 standard error.

events recalled correctly was 1.28 out of 4 (32.2% with a standard error of 3.4%) while the mean for the NoFE questions was 0.92 out of 4 (23.8% with a standard error of 3.1%). The similar trend in *Jungle* did not reach significance. For the *Jungle* story, the mean of the FE-related events recalled correctly was 1.84 out of 4 (46.3% with a standard error of 4.7%) while the mean for the NoFE questions was 1.56 out of 4 (39.6% with a standard error of 4.1%). As the intrinsic saliency of story features is unknown, this cannot be characterized as a ceiling effect. However, the statistical unreliability of the trend may still reflect an effective limit on children's tendency to recall the particular story content signaled by the FE, in the face of other attractive alternative content. For example, when children were asked how they knew they were excited at viewing the tiger, the most common response was essentially, "because I was looking at a tiger." Failure to mention the heartbeat, signaled by the FE here, is hardly surprising.

Reading time

A t-test was performed on the reading time normalized by the number of words, to check if there was any difference between screens with and without FEs present. No significant difference was found between the reading times per word.

Post-reading Survey

Figure 9 shows the result of the survey question related to liking the FEs, where scores ranged from 1 (didn't like at all) to 5 (liked very much). Asked, "If you read a story again, would you like to read it with or without the Feel Effects?" 65% favored FEs. Not all participants wished to name their favorite FE, but among those who did, common favorites were *rain*, *lizard running across my hands*, *roar*, *alarm clock*, *heart beating*, and *mom tapping*.

In response to the request to comment about their experience, many children expressed that they liked the FEs and enjoyed feeling sensations in their hands. One of them said, "It felt really cool. If I was one of them [protagonist], I wondered how it would actually feel. It was like a preview about how it would actually feel." Another said, "It felt really cool in my hands. I just wish that there were more of them." Many children mentioned that they liked the gloves and thought that they were warm and comfortable. One of them said, "I liked that there were gloves and you knew where to put your hands. You didn't have to feel where to put your hands, you could just put your hands in the gloves." Another participant expressed that it felt like a video game with his thumbs clicking the buttons. Another said, "I thought that was really cool, like a leap in technology!"

DISCUSSION AND CONCLUDING REMARKS

The present results provide evidence for two promising influences of haptic FEs during story reading. One is to increase the memory salience of the events paired with FEs, making them more available for recall. The other is to enhance story understanding more generally. These effects emerged clearly in the *Space* story, where the impact on comprehension was a 17% increase in performance. The *Tiger* story was essentially at ceiling in the comprehension test and showed a similar memory-enhancement trend that failed to reach significance, which may also reflect practical limits on performance.

Our within-subjects, within-story experimental design was prepared specifically to minimize the effect of novelty in the study. Had we separated children into groups with and without FEs, those getting the haptic effects might simply be more motivated and pay more attention to the story. In contrast, each participant received the same number of haptic effects, distributed evenly throughout the story among sentences that were not augmented by touch. Furthermore, the first two haptic effects (excluded from the analysis) were always activated to familiarize the child with the sensations and avoid simple effects of surprise or novelty.

Further work is needed to investigate the long-term effects of haptic feedback and to establish the generality of the findings in this study. An important extension is to children who are relatively disadvantaged in reading preparation.

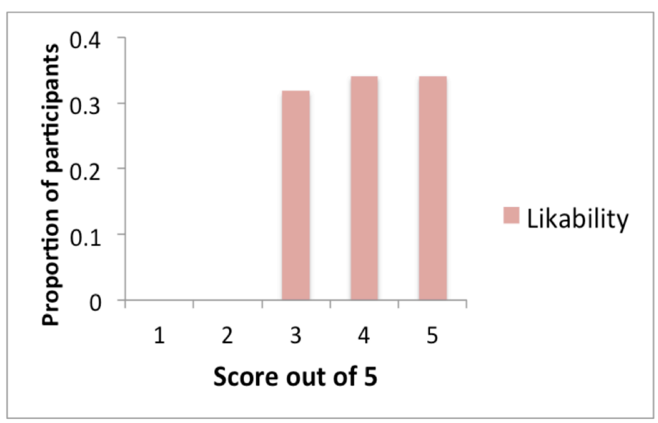

Figure 9. Proportion of children selecting each alternative on the likability scale (1-5, increasing).

The present subjects were generally competent readers, as evidenced by their understanding of gist and the high level of comprehension in the more accessible story. Given that the effect of FE emerged in the story that yielded lower performance overall, it seems possible that effects would be greater for children who are finding reading difficult.

The present approach is amenable to various instructional approaches to reading [23]. The limiting factor is not the reading theory *per se*, but the extent to which children's literary material lends itself to haptic effects. Consistent with approaches where children are encouraged to seek out practice that interests them, the greater engagement and motivation associated with FEs should promote reading activity. Phonics-based reading materials could likewise be enhanced with FEs.

The experiment reported here tested the effect of adding haptic feedback to stories presented as text alone. Another interesting direction would be to explore the effect of haptics in the context of different story materials. Integrating graphics into the stories along with feel effects may further enhance the reading experience. Furthermore, FeelSleeve could be used with other applications on tablets, such as comic books or games, to enhance children's experiences in education and entertainment. Ultimately, our goal is to engage young readers and promote their enjoyment of a variety of textual materials.

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