Using Haptic Inputs to Enrich Story Listening for Young Children

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ABSTRACT

Research on children's cognitive development has demonstrated the positive effects of listening to stories. However, traditional story listening is losing its appeal to other entertainment technology such as video games. Hence, there is growing interest in studying the influence of ancillary media such as sound and interactive effects, although haptic sensory input has remained relatively unexploited. We implemented a haptic vest that generates vibrotactile stimulation related to story content to augment story listening. Study 1 showed that 5- and 6-year olds, but not 4-year olds, could associate haptic effects with semantic interpretations. In Study 2, children listened to stories containing elements with or without haptic effects. The 5- and 6-year olds showed better comprehension of the haptically-signaled content in the higher-performance story. The results provide initial evidence that haptic effects can potentially enhance the reading/listening experience of children beyond 4 years.

Categories and Subject Descriptors

H.5.1 [**Information interfaces and presentation**]: Multimedia Information Systems-Artificial, augmented, and virtual realities

Keywords

Haptics, haptic vocabulary, vibrotactile feedback, story listening technology, haptic vest

1. INTRODUCTION

Listening to stories is an important experience for young children, not only because of its value for entertainment and engaging social interaction, but also because listening sets the groundwork for further development in language function and literacy [6]. Through listening, children expand vocabulary [15], develop an understanding of narrative structure [16], cultivate interest in learning to read [2], and even assimilate social values [1].

Typical children's books incorporate illustrations that engage interest. Illustrations not only enhance memory for story content, but also directly facilitate comprehension [13]. However, as more engaging activities such as computer games occupy children's lives, traditional story listening with only audio and illustrations is slowly losing its appeal [12]. As a result, much effort is spent on using multimodal technology to promote story listening activity [9]. Past research has shown the benefits of multimodality for learning. Students can learn more deeply from a combination of words and pictures than from words alone [11]. More recent technologies that have embedded multiple modalities, e.g., animations and physical interaction, to promote story listening have shown positive effects [5, 14].

Lagging these developments is the use of touch to augment children's stories. This occurs both because touch is currenly not acknowledged as an effective channel for conveying meaning, and because technologies providing inexpensive and reliable haptic inputs are lacking. The present research is a study that seeks to meet these needs. Recent research points to a haptic vocabulary that, while limited, may enrich communicative experience. Earlier approaches include vibrotactile alphabets [4], haptic phonemes [3], and icons [17]. Closer to our method is an attempt to integrate a small set of haptic effects (heartbeat, temperature, pressure) into adult story listening through a vest in sync with the story [7]. However, no similar attempts have been made using haptics in story listening for children.

More recently, Israr and colleagues [8] used an array of haptic actuators on the back of a chair to convey the semantics associated with descriptive language phrases. Their study showed a natural association between haptics and semantics primed by knowledge of the lexicon. For example, "light rain" was exemplified by low-amplitude, spatially displaced, temporally interspersed pulses. Their experiments first developed a haptic vocabulary of 23 such *feel effects*. A subsequent study showed that the resulting effects constituted reliable language/haptic associations that supported synonymy and inference. The study bridged the gap be-

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tween haptics and semantics for adults. Most importantly, it showed that the association between haptics and lexical items is mediated by semantic knowledge. This is crucial because one concern of multimodal learning is attentional demands. As each modality acts as a limited-capacity information channel, multimodal inputs can mutually interfere with cognitive processing and impair learning [11]. However, Israr's study suggests that adding haptic inputs to stories might engage semantic processing without increasing the workload of listening.

Based on this research, we tested whether haptics can benefit young children's story comprehension. The contribution of our study is two-fold. First, we investigate whether children, like adults, can associate haptic patterns with semantic meanings. Assessing this ability across ages 4-6 years was the purpose of Study 1. Given evidence of haptic/semantic associations in the older age groups, we further examined whether haptic augmentation of story listening through a novel vest could facilitate children's story comprehension and memory, and at what ages.

2. GENERAL METHOD

2.1 Participants

Twenty-nine children (10 aged 4 years, 10 aged 5 years, 9 aged 6 years) participated. All completed Study 1, and 27 (9 of each group) went on to complete Study 2. Sixteen (9 aged 4 years and 7 aged 5 years) were recruited through a children's school and the other 13 (1 aged 4 years, 3 aged 5 years and 9 aged 6 years) were recruited from the broader community with IRB approval. Despite the difference in recruiting method, there is no evidence that the difference either heightened or reduced expected effect of age.

2.2 Apparatus

Haptic patterns were presented by means of a custom-made child-size vest with flexible back fabric and open sides, capable of adjustment to allow maximum back contact for a range of chest and waist sizes. A 4 (row) $\times$ 5 (column) array of twenty vibrotactile actuators, or tactors (type C-2, Engineering Acoustics INC., Florida, USA) were sewn into small pockets on the inside of the vest, directly in contact with the child's back. Tactor actuation was achieved via an original iPad Mini application and Wi-Fi communication. The children wore BOSE noise-cancelling headphones to listen to the story and mask motor noises produced by the tactors.

Figure 1: Vest with 20 embedded actuators and story-listening setup

3. STUDY 1: ASSOCIATING HAPTIC PATTERNS WITH SEMANTIC MEANINGS

For Study 1, we hypothesized that children, like adults, can associate haptic inputs with semantic meanings and that this ability would increase with age.

3.1 Stimuli

The stimuli were adopted from a library of feel effects (FEs) tested in a previous study on adult participants by Israr and colleagues [8]. An FE consists of a haptic pattern (HP) paired with a language phrase (LP). The haptic pattern is defined by the number and spacing of active tactors and 4 parameter settings for each tactor: SOA (stimulus onset asynchrony), duration, ramp-up rate, and intensity (converted from the previous logarithmic values to square root values to optimize the haptic sensations on the children's vest). The language phrase is a meaningful description, which may or may not be consistent with the accompanying haptic stimulus.

Children were presented with 15 LP-HP pairs representing four FE categories:

- *Core FEs* 5 LP-HP pairs that emerged in the previous study [8] as their most appropriate instantiation (e.g., "light rain" paired with a series of randomly spaced, low-intensity taps).
- *Mismatches* 6 LP-HP pairs from contrasting FEs (e.g., the phrase "light rain" paired with the haptic values for a single tap that adults associated with "poke").
- *Synonyms* 3 pairs substituting words or phrases with the same meaning for the *Core* LP (e.g., "sprinkle" substituted for "light rain").
- *Inference* a novel LP-HP pair with haptic parameter settings inferred from an HP of a semantically-related *Core* LP (e.g., tactor settings between those of "sprinkle" and "downpour" are used with the phrase "rain").

3.2 Procedure

To introduce haptic sensation and confirm that all tactors could be felt while wearing the vest, the child was asked to indicate the direction of a series of tactor actuations (called a "line") along an edge. The tactors were successfully detected along all edges without exception.

The main task consisted of assessing the LP-HP association for 15 randomly ordered FEs. For each FE, the experimenter read the LP, cued the iPad to play the HP, and then asked the child "Did it feel like [the LP]? Yes or no?". If the response was "yes" the child was asked to indicate how much the HP felt like the LP by responding either "a little" or "a lot"; if a child responded "no" the next trial began. This simple scale was used to accommodate all ages and because it could be easily scored. Any implicit demands to agree with the interviewer would be more likely to affect the youngest children. This raises the possibility that if there is a tendency for the younger children to simply accept items, the method may under-estimate their ability to discriminate appropriate and inappropriate effects.

3.3 Study 1 Results and Discussion

Judgments of the LP-HP association were converted to a 3-point scale with "no" = 0, "a little" = 1, and "a lot" = 2. A 2-way ANOVA was then conducted on the scale values, with the three positive FE types *(Core/Synonym/Inference)* as a within-subject factor, and age as a between-subject factor. There was no effect of FE type, $F(2, 52) = 2.46$, $p = 0.10$, and no interaction of FE type with age, $F(4, 52) = 1.53$, $p = 0.21$. Accordingly, subsequent analyses combined *Core*, *Synonym*, and *Inference* responses into *Matches*.

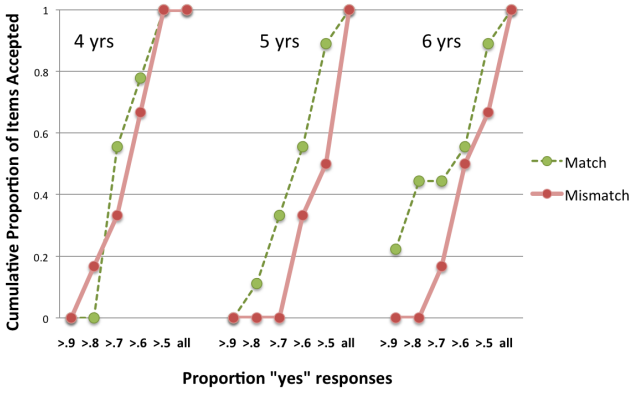

Figure 2: The cumulative proportions of FEs that Match and Mismatch semantic content at differing acceptance criteria for 4-, 5-, and 6-year-olds.

A 2-way ANOVA with *Matches/Mismatches* as a within-subject factor, and age as a between-subject factor showed a significant difference between the *Matches* ($M = 1.10$) and *Mismatches* ($M = 0.95$), $F(1, 26) = 4.50$, $p = 0.04$. The interaction between *Matches/Mismatches* and age did not reach significance, $F(2, 26) = 1.40$, $p = 0.27$, but within-subject t-tests showed that only 6-year-olds reliably rated *Matches* higher than *Mismatches*, $p = 0.01$ (average advantage for *Matches* = 0.31 for 6-year olds vs. 0.03 for 5 years [$p = 0.86$], and 0.11 for 4 years [$p = 0.36$]). The data also indicate that some FEs intended as good LP-HP matches were not accepted as such. FEs with HPs for "poke" and "swipe" (both brief), in particular, reached only 55% and 58% agreement across groups.

Increasing differentiation of items as a function of age can be seen in Figure 2, which shows the cumulative proportion of FEs that children accepted as related in the initial yes/no test, at differing criteria for acceptance (proportion of children agreeing on "yes"). At 5 and 6 years, *Match* and *Mismatch* populations clearly diverge, whereas the 4-year olds simply tend to accept most items.

We compared the children's mean ratings for the nine *Matches* with mean ratings for the same FEs by adult participants in Israr and colleagues [8]. The correlation increased across age groups: $r = 0.30$, 0.42, 0.71, for 4-, 5-, and 6-year olds, respectively, with the 6-year olds significant at $p < 0.05$.

Overall, the rating data indicate a gradual progression of developing language-haptic associations with age, with 6-year olds similar to adults. Four-year olds showed little sensitivity to the congruence of haptic/semantic pairings, suggesting that 5- and 6-year olds are the best candidates for augmenting story comprehension and memory with haptic effects. Testing this possibility was the purpose of Study 2.

4. STUDY 2: EFFECT ON CHILDREN'S STORY COMPREHENSION

Given that the 5- and 6-year-olds showed the ability to associate haptics and semantics, we hypothesized in Study 2 that embedding haptic patterns would enhance 5- and 6-year-olds' story comprehension and memory.

4.1 Stimuli

Children listened to two four-minute long stories written by a professional children's story writer and recorded by an actress with experience in children's theater. The stories were written in the first person and although they had different content, they shared the same story arc and were matched for word count. One story (hereafter, "Tiger") put the listener in the place of a jungle explorer searching for a legendary silver-striped tiger. The tiger is purported to be large and ferocious but, upon discovery after a number of interim events, turns out to be small and friendly. The other story (hereafter, "Space") placed the listener in outer space, delivering a package to Saturn by space ship. After a series of events, the protagonist reaches his/her destination only to discover he/she has been carrying his/her own birthday cake to a surprise party thrown by family and friends. Each story contained 7 locations with potential FEs, (corresponding to run, swipe, purr, poke, rain, heartbeat, and tap), dispersed at approximately equal intervals. The HP associated with each FE was drawn from the previous adult study [10] but adapted in length of onset to fit the pace of the story recording and maximize the semantic match between LP and HP. Thus, for example, the Tiger sentences "I love walking in the jungle, even when it's raining. Rain won't stop me!" were accompanied by the previously validated HP for "light rain" with the onset of the effect starting at "even" and continuing through "me."

Only four of the seven FE locations were active in a given story, allowing for within-subject comparison of comprehension and memory for content either accompanied by or lacking an FE. The first and last location was always active, and the two additional active locations were chosen so that across all children and conditions, all FEs were active equally often. Children were assigned to four conditions, counterbalancing story order and active FEs.

Nine comprehension questions (four related to FEs, five unrelated) were constructed for each story, using phrasing that contained keywords to cue story recall. Children were instructed first to answer spontaneously, and if this failed (the child asked for help or remained silent for more than five seconds), they were given a second opportunity to answer using a three-alternative multiple-choice format.

4.2 Procedure

Study 2 was conducted after a break following Study 1. To accommodate the school's policies, the break was 24 to 48 hours long for children recruited from the children's school.

Children recruited from the community had a 10-minute break, allowing completion in one session.

Fit of the vest was confirmed as in Study 1. The child then listened to the first story, after which he or she was asked to summarize it; this was audio recorded for future analysis. After summarization, the experimenter asked the nine comprehension questions, and then the procedure repeated for the second story.

4.3 Study 2 Results and Discussion

Responses to the story comprehension questions were scored as correct, whether by spontaneous recall or subsequent prompted recognition, vs. incorrect. Consistent with their insensitivity to LP-HP semantics in Study 1, the 4-year olds showed no advantage in proportion correct for FEs ($M_{FEactive} = 0.65$, $M_{FEabsent} = 0.65$).

Accordingly, the analysis of the effect of haptic content focused on the 5- and 6-year olds. An initial analysis by age, story, and FE status indicated that responses were significantly more accurate for Tiger (M = 0.78) than Space (M = 0.50), F(1, 16) = 7.58, p = 0.01. There was also an FE status × story interaction, F(1,16) = 8.41, p = 0.01. Given this substantial difference in performance, separate ANOVAs were conducted on the two stories with factors age (5 and 6) and FE status. For Tiger, there was a significant advantage when an FE was active (M = 0.78 vs. 0.62 for active vs. inactive), F(1,16) = 8.23, p = 0.01, which did not interact with age. There was also no effect of age. Space, in contrast, showed no effects (M = 0.50 vs. 0.62 for active versus for inactive), all p values > 0.05. Re-examination of Space and its questions suggests that comprehension performance may have suffered both because the tested content contained elements that were not central to the story and because the active FEs included "poke" and "swipe," which were rated more poorly in Study 1.

The story summaries were segmented by two independent coders into communication units [10], each assigned to a corresponding line in the story. Coder agreement was 97% ($\kappa = 0.92$). An ANOVA on number of units by age and story, including 8 subjects of each age who summarized both stories, showed only an effect of age, F(2,24) = 7.63, p < 0.05; M(4) = 1.10, M(5) = 4.70, M(6) = 9.10. The nonsignificant effect of story (M = 5.70 units for Space vs. 4.20 for Tiger) supports the idea that the poorer performance on comprehension for Space may reflect the particular haptic content and test items rather than the story per se.

5. CONCLUSIONS AND APPLICATIONS

The present studies are the first to establish that 6-year-olds, and potentially even younger children, have an adult-like ability to associate haptic input with lexical content. This lays the critical foundation for using haptic inputs to enhance semantics. Data from Study 2 suggest that this ability can potentially facilitate story comprehension in 5- and 6-year-olds. The data showed that facilitation of story understanding was obtained under a novel, added information channel, in contrast to what others might predict based on multimodal competition. However, the improvement could stem from multiple sources, including a novelty effect specific to content accompanied by FEs. Further research is needed to understand the mechanism behind the improvement in story comprehension.

The current work also suggests exploring the use of haptics with older children and in other narrative environments. Active reading could replace story listening with a similar paradigm in older children. The use of FEs can further be extended to other media, such as graphical stories, and could be integrated with other sensory modalities, particularly the auditory sense. Our ultimate goal is to enhance the experience of reading for children and by doing so, facilitate their cognitive development.

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