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Contingent Responsiveness in Digital Storybooks: Effects on Children's Comprehension and the Role of Individual Differences in Attention

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Abstract

Experiences of contingent interactions like referential cues (e.g., caregivers pointing to relevant text and pictures) during shared book reading predict better reading and language outcomes (Landry, & Smith, 2007). However, it is unclear whether contingent responsiveness in a digital book could provide similar support for children in the absence of contingent feedback from an adult. The effects on story comprehension using an interactive book with content-related animations that activated contingent on children's vocalizations were investigated, with a focus on whether the interactive book might be especially useful for children with less developed attentional control. The present study used a within-subject design with data from 69 preschool-aged children. The use of the interactive book exhibited significantly increased comprehension, and was also found to be especially useful for children with less attentional control. Importantly, the associations between attention and comprehension gains were not entirely due to variance shared with verbal ability.

Keywords: attention; reading; individual differences; reading comprehension; books, technology, learning

Introduction

A critical determinant of establishing a communicative relation between an adult and child is the presence of contingency—that is—the feedback the child receives is dependent upon their behavior (Bornstein, Tamis-LeMonda, Hahn, & Haynes, 2008). In the context of spoken language, a contingent interaction is when an adult responds specifically, immediately and appropriately to a child's vocalizations. Contingent responsiveness to children and following their lead allows children to feel in control, maintains their focus, and encourages them to continue the interaction when each of their vocalizations is met with an immediate response (Hirsh-Pasek et al., 2015). Contingent caregiver behavior complements and extends children's capacities, and is positively associated with emerging cognitive and language competence (Sohr-Preston & Scaramella, 2006).

A common activity that promotes contingent interaction is shared book reading. Experiences of contingent interactions

during shared book reading predict better reading and language outcomes (Landry, & Smith, 2007). The role of contingency is especially important during shared book reading because children are given the opportunity for conversational turns that lay the groundwork for literacy skills: children practice vocalizing the story text, and adults facilitate children's understanding of the story by pointing to relevant story content such as pictures and text that match the pronounced words (Ezell, Justice, & Parsons, 2000; Hargrave & Sénéchal, 2000). For example, consider the following: a caregiver is reading a book to a child and after the caregiver reads, "car" the child practices saying the word aloud. Responding contingently to the child's vocalization, the caregiver points to the text "car," along with the car illustration. By providing these referential cues, the caregiver indicates to the child that the pronounced word "car" is related to the car text and picture. This nonverbal feedback may facilitate children to internalize features (congruent text and pictures) of the pronounced words, and enables them to later reproduce an understanding about the words in relation to the story (Mason, 1990).

Children's earliest experiences with books are no longer limited to paper, and books are now accessible in the form of digital books through computers, apps, and tablets. Researchers have explored the issues related to young children's experiences with digital books and have found that interactive features often negatively affect learning (Krcmar & Cingel, 2014; Parish-Morris et al., 2013). One likely reason that current designs of interactive books lead to worse learning outcomes is because the interactive features do not provide the contingent nonverbal feedback adults provide to children that promotes story comprehension.

Although contingent responsiveness is easily achieved in face-to-face interactions, imbuing contingency in child-to-digital device interactions is a challenge and the effects on learning are understudied. The goal of the current study was to investigate whether contingent responsiveness in an interactive book would enhance preschool-aged children's story comprehension. More recently, digital devices are

capable of contingent interactions by responding to the actions of people through speech. Speech recognition technology is a core element of user interface design in the field of human-computer interaction, and can be used as a tool to improve literacy (Kalil, 2012).

We examined whether the addition of content-related text and pictures that animate contingent on child vocalizations (i.e., animations activate only when the child says a word from the story aloud: child says, “car” and both a picture of a car and the word car animates by popping off the page), would increase story comprehension compared to a board book and a book without interactive features (static digital book). We hypothesized that the addition of contingent interactivity modeled from high quality human interactions would increase learning outcomes. We also examined if this type of interactivity in books might be especially useful for children with less developed attentional control. While prior research has found that interactive features are distracting and detract from learning, caregiver behavior characterized by high levels of responsiveness has been found to buffer poor attention regulation in children (Graziano, Calkins, & Keane, 2011). Therefore, we hypothesized that the addition of story-related pictures and text that animate contingent on children’s vocalizations would be especially beneficial for children who are easily distracted. That is, because of these children’s limited ability to focus on relevant material while suppressing extraneous information, they are the ones who might benefit the most from referential cues to story-related text and pictures that match their vocalizations.

Experiment 1

Method

Participants The study used a within-subject design with data from 35 children (16 boys, 19 girls) ages 4 to 5-years-old ($M = 4.94$ years, $SD = 8$ months). All participants were recruited from the same laboratory school on the campus of a private university in Pittsburgh, Pennsylvania. Children were tested individually by trained research assistants. An additional child was tested but excluded due to equipment failure ($n = 1$).

Design and Procedure

Book Selection To maintain a high level of ecological validity, children were read commercially available books designed for beginner readers written and illustrated by Thacher Hurd: *Cat’s Pajamas* and *Zoom City*. Children were read each story in the presentation of a board book or interactive digital book. Order (interactive book; board book) and story (*Cat’s Pajamas*; *Zoom City*) were randomized and counterbalanced. The board book versions of the stories were converted into digital copies with the addition of contingent interactive features. The features of the interactive book were content-related animations that activated contingent on the child’s vocalizations. Hypotheses-blind research assistants listened to session recordings and coded story comprehension performance.

After each story, children were asked ten questions to assess story comprehension. An independent measure of attention was administered to children prior to the second book reading. During subsequent lab visits, a measure of verbal ability was administered. Additional details regarding each measure are provided below.

All sessions took place in the same testing room that allowed for detailed audio and video recordings. The reader in the reader-child dyads was a trained hypothesis-blind research assistant that was instructed to solely read the books aloud to participants, and to refrain from prompting, scaffolding, or otherwise interacting with the children during the book reading portion of the procedure (unless the child indicated a desire to quit, which none did). For both book presentations, the reader started each session by reading the first line of the story, and then said “Now it’s your turn!” to the child. This way—for both conditions—children were given the exact same directions before each book presentation.

The interactive digital book was presented to children on an Apple iPad (9.4 in x 6.6 in). The interactive and board book versions were identical in pictures and text, but were displayed on different platforms. In the interactive digital version, the text grew in size simultaneously with a short (500 ms) animation when words from the narrative were vocalized by the child. Immediately after the child pronounced words from the narrative, the animation stopped and the text shrunk back to its original size. The interactive book responded only to the child’s vocalizations, not the reader’s. Animations represented the meaning of verbs and nouns in the text (see Table 1). For example, when children vocalized the text from *Zoom City* “fix the headlight,” the animation of a wrench turning generated when the word “fix,” was vocalized and the animation of the car’s headlight flashing on and off generated when the word “headlight” was vocalized. These interactive features were modeled based on how adults contingently respond to children during shared book reading by pointing to the related text and illustrations contingent on the child’s vocalizations (Justice & Kaderavek, 2002).

Table 1: Average animated nouns and verbs per page

Book	Pages	Nouns	Verbs
Zoom City	14	$M = 3.83$	$M = 3.00$
Cat’s Pajamas	14	$M = 4.14$	$M = 3.29$

Story Comprehension Measure At the end of each book presentation children were asked questions that probed their memory for details about the story. Children were asked 10 questions for a total of 15 points for each story about the setting, main characters, plot, theme, and resolution. There were eight 1-point questions, two 2-point questions and one 3-point question. For example, in *Zoom City* the main character fixes the bumper, headlight, and engine on a car. For the 3-point question, children were asked to recall which parts on the car were fixed. Children could receive

full credit if in their response they identified the 3 car parts that were fixed, 2 points if they identified 2 parts, 1 point if they identified 1 part, and 0 points if they failed to recall the parts that were fixed or provided an incorrect response. Similarly for scoring, in *Cat's Pajamas* the main characters make music using drums, cans, and a horn. For the 3-point question, children were asked to recall which instruments were played. Children could receive full credit if in their response they identified the 3 instruments that were played, 2 points if they identified 2 instruments, 1 point if they identified 1 instrument, and 0 points if they failed to recall the instruments that were played or provided an incorrect response. Story comprehension was measured as the percentage of correct responses (out of 15 possible points).

Attention Measure Between the reading sessions, children participated in a visual cancellation task in which they were asked to maintain selective attention and focus on targets with speed and accuracy among other objects (distractors). In this modified version of the NEPSY subtest (Cuevas & Bell, 2014), children were asked to click on target stimulus among distractors as quickly as possible in 180 seconds. Performance on the attention task was calculated using the number of distractors relative to total responses and the total amount of search time to complete the task to measure children's ability to stay on task without getting distracted, and fluently with speed. Engagement was measured as the percentage of time children spent looking at the book presentation out of total reading time. Paired samples *t*-tests indicated that there were no significant differences in the amount of time children spent looking at the interactive book compared to the board book or static book (all $t_s < 1.62$, all $p_s > .12$). Therefore, the primary measure of attention for subsequent analyses was the independent measure of attention, not total looking time at book presentation.

Verbal Ability Measure The Peabody Picture Vocabulary Test (PPVT-IV; Dunn & Dunn, 2007) is a nationally standardized instrument and was administered during a subsequent session within 3 weeks of the initial lab visit.

Results

Effect of book presentation on Story Comprehension

Performance on the story questions was scored twice by hypothesis-blind research assistants who received extensive training using the audio recordings of each session. Audio recordings were used to ensure coders were blind to the book presentation the child was exposed to when answering the questions. Inter-rater reliability using Cohen's kappa (Cohen, 1960) was .86, indicating substantial coder consistency. Children's comprehension scores were significantly higher in the interactive book condition ($M=55.81\%$) than in the board book condition ($M=44.00\%$), paired-sample $t(34)= 5.67$, $p<.001$ (Figure 1); this effect was large, Cohen's $d = 0.97$. Independent samples *t*-tests were used to ensure the differences in story comprehension were not biased by book presentation order and/or storylines

(all $t_s \leq 1.4$, all $p_s > .79$). Taken together, these results indicate children were better able to answer questions assessing comprehension after being read to from the interactive book compared to the board book, regardless of the story or order in which the books were presented.

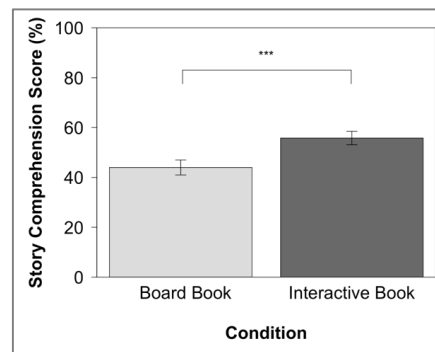


Figure 1: Percentage of correct answers on the story questions as a function of book presentation. *** $p < .001$.

The role of individual differences in attention and book presentation

We examined whether the use of the interactive book might be especially useful for participants with less developed attentional control. For this analysis, we examined the relation between attentional control and comprehension gains using the interactive book. A difference score for each child was calculated by subtracting the board book comprehension score from the interactive book comprehension score to create the variable: *Comprehension Gains*. Difference scores ranged from -28.57% to 85.71%, with a mean of 28.46% ($SD=24.86\%$). Proportion of incorrect responses and search time from the attention task were standardized using Z-scores and averaged together to create the composite variable: *Distractibility* ($M=.13$ $SD=.82$). A score of 0 indicated a score equal to the overall mean (an average performer on the attention task), and higher scores indicated higher distractibility. Children's distractibility was positively associated with improvement in comprehension using the interactive book ($r(35)=.62$, $p<.0001$) as shown in Figure 2. As children's measure of distractibility increased, they showed more benefit in comprehension from using the interactive book.

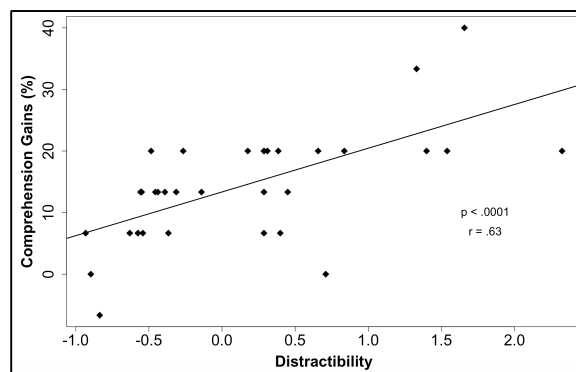


Figure 2: Association between distractibility and comprehension gains. Pearson's $r = .63$.

Unique relation of attentional control to comprehension gains To ensure that the findings were not entirely due to variance shared with verbal ability, 26 participants returned to the laboratory and were administered the PPVT-IV to assess participants' verbal ability ($M=117.65$, $SD = 12.83$). Table 2 presents the results of separate regression equations predicting comprehension gains using the interactive book with the predictors distractibility, age, sex, and verbal ability. The equations present estimates of the unique effect of each variable on the outcome adjusted for all other terms in the model. Results indicated that distractibility makes a significant contribution to comprehension gains using the interactive book.

Table 2: Relation of Attention to Comprehension Gains

	β	SE	t
Distractibility	8.65***	1.88	4.59
Verbal Ability	0.02	0.08	0.30
Age	3.56	3.71	0.96
Sex	-0.16	3.36	-0.04
R^2	0.53		
F	7.98		

*** $p < 0.001$, ** $p < 0.01$

Experiment 2

The goal of this study was to ensure the results from Experiment 1 were not solely because exposure to a book on a digital platform is superior to a board book, perhaps due to a novelty effect. To assess this possibility, in Experiment 2 we present both an interactive and a non-interactive story via the iPad.

Method

Participants The study used a within-subject design with data from 34 children (21 boys, 13 girls) ages 4 to 5-years-old ($M = 4.52$ years, $SD = 6$ months). All participants were recruited from the same laboratory school in Pittsburgh, Pennsylvania and none participated in Experiment 1.

Design and Procedure

Book Selection The procedure and measures were identical to Experiment 1, except the control condition was a static digital book presentation: the pictures and text remained motionless and did not animate contingent on children's vocalizations. Both versions were identical in pictures, text, and platforms (Apple iPad 9.4 in x 6.6 in), but the interactive book had the additional contingent features described in Experiment 1. Order (interactive book; static book) and story (*Zoom City*; *Cat's Pajamas*) were randomized and counterbalanced.

Results

Effect of book presentation on Story Comprehension

Children's comprehension scores were significantly higher in the interactive book condition ($M=61.76\%$) than in the static book condition ($M=41.96\%$), paired-sample $t(33)=8.26$, $p<.001$ (Figure 3); this effect was large, Cohen's $d=1.42$. Inter-rater reliability was $k = .82$, indicating substantial coder consistency of performance on the story questions. Independent samples t -tests indicated there were no order effects (all $ts<.69$, all $ps>.53$). The use of the interactive book resulted in higher story comprehension, consistent with the results of Experiment 1.

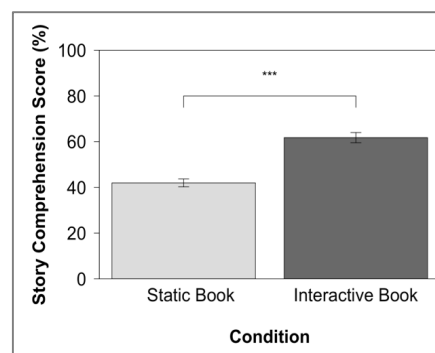


Figure 3: Percentage of correct answers on the story questions as a function of book presentation. *** $p < .001$.

The role of individual differences in attention and book presentation

With the goal of replicating results from Experiment 1, we examined whether the use of the interactive book might be especially useful for participants with less developed attentional control. We applied the same calculations from Experiment 1 to compute *Distractibility* ($M=.07$ $SD=.87$), and *Comprehension Gains* by subtracting the static book comprehension score from the interactive book comprehension score for each child. Difference scores ranged from 0.00% to 53.33%, with a mean of 19.80% ($SD = 13.97\%$). Replicating results from Experiment 1, children's distractibility was positively associated with improvement in comprehension using the interactive book ($r(34)=.63$, $p<.0001$), as shown in Figure 4.

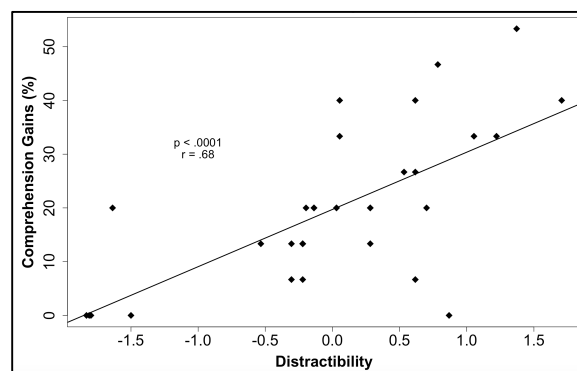


Figure 4: Association between distractibility and comprehension gains. Pearson's $r = .68$.

Unique relation of attentional control to comprehension gains Thirty-one participants returned to the laboratory and were administered the PPVT-IV to assess participants' verbal ability ($M=117.90$, $SD = 15.54$). Table 3 presents the results of separate regression equations predicting comprehension gains using the interactive book with the predictors distractibility, age, sex, and verbal ability. Results indicated that distractibility makes a significant contribution to comprehension gains using the interactive book.

Table 3: Relation of Attention to Comprehension Gains

	β	SE	t
Distractibility	11.43***	2.07	5.52
Verbal Ability	0.05	0.07	0.87
Age	4.65	2.99	1.55
Sex	3.28	3.79	0.87
R^2	0.45		
F	7.81		

*** $p < 0.001$, ** $p < 0.01$

The results replicated findings from Experiment 1 and indicate that distractibility is positively associated with comprehension gains, and accounts for the unique variance in comprehension gains independent of verbal ability.

Manipulation check We investigated whether children's story comprehension benefited from the contingency of the interactive features, or the congruent animations that matched the story narrative. We replicated Experiment 1 and 2 with the control condition of an animated digital book presentation with another group of children from the same laboratory school ($n = 21$). The experimental condition was the interactive book with the contingent features identical to those described in Experiment 1 and 2. The animated digital versions of *Zoom City* and *Cat's Pajamas* were the digital versions of the books, without the addition of contingency: the picture and text animations were deployed for each page, but did not animate contingent on the vocalizations of the child. Children's comprehension scores were significantly higher in the interactive book condition ($M = 53.97\%$) than in the animated book condition ($M = 39.37\%$), paired-sample $t(20)=9.74$, $p<.001$. Additionally, children's distractibility was positively associated with improvement in comprehension using the interactive book ($r(21) = .44$, $p < .0001$). Results indicate that the addition of the contingent interactive features benefited children's comprehension beyond just animations.

Discussion

These data provide the first systematic analysis of whether contingent nonverbal feedback from a digital book could provide supportive referential cues for children and improve story comprehension. There were significant differences in

comprehension, with the use of the interactive book compared to a board book. Our findings were strengthened when these results were replicated in a second experiment comparing the use of the interactive book with a static digital book, discarding the possibility that exposure to the interactive book was superior to the board book due to a novelty effect. Furthermore, it was shown that the animations were not driving the effect in a follow-up control experiment comparing the use of the interactive book with an animated digital book. Similar to the effects contingent responsiveness from adults have on children during shared book reading, when each of the children's vocalizations was met with the immediate feedback of corresponding text and picture animations, this enabled them to later reproduce a better understanding about the story.

Our findings indicate that the interactive contingent features were especially useful for children with poor attentional control. Importantly, our analyses indicated that distractibility is positively associated with comprehension gains, and also accounts for the unique variance in comprehension gains independent of verbal ability for both experiments. Children's attentional control and ability to focus are significant predictors of reading achievement not only when they enter formal schooling, but continue to predict reading achievement until several years later in development (Guo, Connor, Tompkins, & Morrison, 2011; McClelland, Acock, & Morrison, 2006). Attention—a foundational component linked to school readiness and reading achievement—should be taken into account when designing digital tools intended to foster learning. Findings from this study highlight the importance of examining individual differences in attention and shifts the study from characterizing group means to characterizing individual differences and predicting outcomes.

The current design of interactive digital books may create the constant switching between two different tasks: understanding the story on one hand and exploring entertaining features on the other. This might place too much extraneous load on the working memory of young children and result in decreased story comprehension (Mayer & Moreno, 2003; Takacs, Swart, & Bus, 2015). Because animations matched the simultaneously pronounced story text in the interactive book, children were not forced to constantly switch between the animations and narrative and instead the visuals helped integrate nonverbal information and language.

A future direction to pursue is gaining a thorough understanding of the effects of the interactive contingent features for different groups of at-risk children like low SES; second language learner immigrants; children with learning disabilities, and developmental delays. Early-in-life inequalities point to the need for substantial interventions to reduce them. Digital books—with well-controlled studies on the effectiveness of their features—can potentially be used as intervention tools so that children arrive in kindergarten ready to learn and are not at a disadvantage compared to other students.

The present findings extend our understanding of effective interactive features in digital books that will optimize these formats and content on preschool children's learning. This is especially crucial for this age group because 72% of top-selling paid apps in the Education category of the iTunes Store target preschool-aged children, and apps for the preschool age category have exhibited the greatest growth compared to all other age groups (Shuler, Levine, & Lee, 2012). Thus, there has been substantial interest in the development and effectiveness of digital devices designed to improve emergent literacy skills during early childhood.

Media use by preschool children may not be by itself the critical concern; however, poorly designed educational devices might be. If a caregiver were reading a book to a child, it would seem obvious that stopping the child in the middle of the page to play a game or make an irrelevant noise would interrupt the flow of the story and distract the child from understanding the narrative. Yet, this is how many interactive digital books are designed: with amusing sound effects and animations activated spontaneously on the story pages (Guernsey, Levine, Chiong, & Severns, 2012). When well-deployed and designed, interactive features in digital devices have the potential to enrich, not hinder learning experiences for children.

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