Bilingual Children’s Visual Attention while Reading Digital Picture Books and Story Retelling

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**Introduction**

Picture book reading is one of the most critical approaches to promote children’s early language and literacy development (Bus, van IJzendoorn, & Pellegrini, 1995; Mol & Bus, 2011; Sun, Bornstein, & Esposito, 2021; Sun & Ng, 2021; Sun & Yin, 2020). However, young children may need support to maximally benefit from pictures for understanding narratives that often include sophisticated words and complex grammar (Montag, Jones, & Smith, 2015; Sun, Toh, & Steinkrauss, 2020; Sun & Verspoor, 2020). In line with multimedia learning theory, pictures in storybooks provide nonverbal representations of the narrative thread and the plotline, thus facilitating narrative understanding (Takacs & Bus, 2016). Viewers listening to an oral narration fixate objects even during pronunciation or immediately after hearing words (Eberhard, Spivey-Knowlton, Sedivy, & Tanenhaus, 1995). By concretizing story events, children are more successful in storing and retaining the story language and its meaning (Verhallen & Bus, 2011). In other words, the way children pay visual attention to the illustration is an essential indicator of processing the storyline.

Experimental digital books may integrate motion and camera movements into the picture book design, and there is evidence that such affordances are effective in promoting children’s total fixation time (Sun, Loh, & Roberts, 2019; Takacs & Bus, 2016). Compared to the static illustrations in paper books, these digital books effectively promote comprehension as they help young readers benefit from the pictures. Additional features, including motion and built-in camera movement, direct children’s visual attention to details of the illustration that help them understand the narrative (Bus, Takacs, & Kegel, 2015; Verhallen & Bus, 2009).

Previous studies showed effects on the outcomes of reading enhanced digital books (e.g., story comprehension, vocabulary acquisition), but much less is known about the impact on children’s visual attention over repetitive readings. The present study compares children’s visual attention when reading enhanced digital books and the equivalent static book over repetitive readings to test if the guidance of visual attention via illustrations facilitates children’s story comprehension. We also explore how children’s language proficiency affects their visual attention across readings.

## Cognitive Theory of Multimedia Learning

The cognitive theory of multimedia learning is grounded in various cognitive principles of learning (Mayer, 2009) and helps explain how motion and camera movements can influence learning (Bus, Roskos, & Burstein, 2021). The first cognitive principle suggests that we can expect better learning effects when both channels, auditory and visual, are included (multimedia learning principle), and information in both channels is presented near to, rather than far from, each other in time (temporal contiguity principle). The second cognitive principle posits that since each channel has a limited capacity for processing information at the same time, extraneous material should be excluded rather than included. A version that guides the reader’s visual attention may reduce the risk of cognitive overload due to redundant information. The third cognitive principle entails that learners actively engage in processing the story (Mayer, 2009). Multimedia features arouse curiosity while they read the story, thereby promoting active processing. Take the following example from the story *Little Kangaroo*: In the story, Mama Kangaroo encourages Little Kangaroo to walk on her own and to actively discover the world herself. In the still image of the first scene, Little Kangaroo is visible all the time. By contrast, in the digital version, Little Kangaroo emerges later from the pouch, arousing curiosity by first showing Mama Kangaroo looking exhausted.

The target books include details in motion, built-in camera movements, and sound and music to facilitate the use of pictures in understanding the story (Bus et al., 2015). In “still” picture books, illustrations include numerous details that may be difficult to disentangle, especially for children for whom the narrative is difficult to understand. Enhanced pictures, by contrast, support children’s understanding of the story character’s goals, motivations, and emotions (Verhallen, Bus, & de Jong, 2006) and enable incidental word learning probably due to improved story comprehension (Verhallen & Bus, 2010). In the same vein, Mandarin enhanced digital books facilitate 4-5 years old bilingual children’s Mandarin vocabulary production, novel word context integration, and story retelling (Sun et al., 2019).

## Children’s Visual Attention in Enhanced Digital Books Exposure

Unlike prior studies using eye-gaze methodologies (Evans & Saint-Aubin, 2013; Justice, Meier, & Walpole, 2005; Justice, Pullen, & Pence, 2008), we test whether adding motion, camera movements, and sound affects the visual attention to the screen. Takacs and Bus (2016) registered 4- to 6-year-old children’s visual attention to illustrations while listening to the narrative and found that children focus longer and steadier when details are in motion, despite that these pictures were not more informative than the static pictures. Sun and colleagues’ (2019) findings confirmed that the average fixation time to the screen increased with motion and camera movements. We assume that the insertion of motion and camera movements guides children’s attentional orientation, as they are naturally drawn to socially relevant (e.g., faces) and visually salient features (e.g., motion) (Kadooka & Franchak, 2020). Infants and preschool children’s attentional development “involves a bootstrapping process in which attention capturing environmental properties such as salient local motion initially recruit spatial orienting mechanisms” (Ristic & Enns, 2015, p. 25). The appearance of a new object and its associated motion transients enables children to parse objects from its background and successfully locate their gaze for better comprehension (Mital et al., 2011). Note, however, that all additions in digital books are motivated by the story content, not by supporting perceptual processes or highlighting word meanings. The additions, probably also involving music and sounds, are assumed to facilitate deeper processing of the illustration's relevant information, as indicated by longer-delivery eye-fixations (Rayner, 2009).

When visual attention depends on the child’s existing knowledge, schemas, and expectancies (Anderson & Smith, 1984; Calvert et al., 1982), visual attention may decrease with every replay, further familiarizing the child with the story. Huston and Wright (1983, 1989) explicitly argued that attention may follow an inverted U-shaped function related to, among other things, familiarity with the content. In other words, visual attention for an unfamiliar but somewhat understandable story should increase with repetition until the program becomes optimally comprehensible. Beyond that point, when the content becomes overly familiar and predictable, visual attention may decrease. It is possible that children with lower language proficiency may have problems matching the narrative with pictures and show a relatively low level of visual attention from the beginning of the reading. Previous studies on children’s TV viewing (Anderson et al., 1981; Lorch & Castle, 1997) indicated that if the watching materials were beyond children’s comprehension level, they would attend significantly less to the screen. To the children with lower language proficiency, the enhanced pictures may be particularly beneficial as the animated features would facilitate a match between words and pictures and thus promote this group’s visual attention. Children’s attention may increase or stabilize when they experience the book as supportive.

In summary, we expect the following outcomes in the current study:

1. If features like motion and camera movements guide visual attention, young children should pay more visual attention to the screen than to books without these features.
2. With every replay of the story, children become more familiar with the content and plot, resulting in a gradual decrease in their visual attention.
3. By contrast, relatively low language proficiency children may maintain or even increase their visual attention after replays, especially when the books’ enhanced features guide their visual attention to relevant details.
4. Visual attention is related to children’s story comprehension: the more visual attention they pay to the book, the better their story retelling will be.

Methods

## Participants

We have recruited 116 Kindergarten 1 children for the experiment. Eligible children met the following criteria: 1) children were English-Mandarin emergent bilinguals, excluding those who had recently migrated from China, 2) based on parental reports and teacher observations, participants did not have a history of developmental delays or impairment, and 3) participants had to complete no less than two repetitive readings and finish most outcome assessments to be included in the final analyses. Based on the criteria above, we had excluded 27 children, leaving a final sample size of 89 children between the ages of four to five years old. There were 79 children from PAP Community Foundation kindergartens, the largest kindergarten and childcare center operator in Singapore. In addition, we recruited 10 children from non-profit kindergartens. All children were bilinguals and learning Mandarin and English at school. The general instruction (e.g., teaching maths and science) is conducted in English in class.

There were 43 boys and 46 girls in the sample, mainly from middle income families. On average, parents possessed a polytechnic or bachelor’s degree as the highest degree, with approximately S$7500 to S$7999 family income per month. The average monthly household income was lower than the median monthly household income in Singapore in 2017 but far above the poverty line ($2,500 SGD; Donaldson, Loh, Mudaliar, Kadir, & Wu, 2013).

## Design and Reading Materials

We assigned the children to three reading conditions: 1) digital reading with visual and auditory enhancements (+motion/camera movements + sound; Enhanced1 condition), 2) digital reading with auditory enhancements (still images + sound; Enhanced2 condition), and 3) the static digital reading group (still images and no sound; Static condition). (Justice, Meier, & Walpole, 2005; Verhallen, Bus, & de Jong, 2006). There were 32 participants in the Enhanced1 condition, 29 participants in the Enhanced2 condition, and 28 participants in the Static condition.

We focused on fictional picture books, namely *Little Kangaroo* (LK; Genechten, 2007), *Copy-cats* (CC; Veldkamp, 2006), and *Cycling with Grandpa* (CWG; Boonen, 2004), equipped with the above-described features. We used published Mandarin versions of *Little Kangaroo* and *Cycling with Grandpa*, and the first authortranslated *Copy-cats* into Mandarin. *L**i**ttle Kangaroo* is a story about a mother kangaroo who encourages her daughter to become independent by showing her how exciting the outside world is. *Copy-cats* describes how a boy and his parents help their monkey neighbors to avoid the zookeepers. *Cycling with Grandpa* tellsan adventure of a group of children cycling with their grandfather. There are 723 Chinese characters and 30 sentences in *Little Kangaroo*, 1031 Chinese characters and 68 sentences in *Copy-cats*, and 2034 Chinese characters and 97 sentences in *Cycling with Grandpa*.

The story’s content, the illustrations, and the voice of the read-aloud were identical in the enhanced and static versions of the picture books. The static version consisted of scanned illustrations from the original hardcopy picture books. The story text was automatically read aloud, and the story continued automatically to the next screen. In the enhanced versions, the illustrations representing the story events included motion, camera movements (zooming in, panning), and/or sound (music and environmental sounds). For instance, one of the picture books in our study, *Little Kangaroo*, has a scene where Mother Kangaroo invites Little Kangaroo to dance with her to the tunes sung by birds. Little Kangaroo orally turns down the proposal because she thinks the birds are noisy. However, her foot unwittingly moves to the rhythm of the tunes. With motion, zoom, and sound, the enhanced version depicts the whole scenario: Mother Kangaroo dances happily with birds singing and chirping on the trees, and Little Kangaroo refuses to join in but moving her foot to the rhythm of the birdsongs, reflecting her ambivalent attitude. In the static eBook version, only Mother Kangaroo’s dancing pose has been clearly depicted in the illustration, and the conflict between Little Kangaroo’s verbal and body language is not apparent.

There were only slight variations between the two versions in total reading time. For instance, the enhanced version of *Little Kangaroo* lasted 245 seconds compared to 249 seconds in the static conditions. We have corrected the differences in length by dividing total fixation durations for each book by the story’s length, obtaining a percentage score (here referred to as Visual Attention Score).

## Procedure

The experimenters were three trained Mandarin–English bilingual research assistants who majored in psychology or linguistics. Before the experiment, we assessed participants’ English and Chinese vocabulary and grammar. The eligible children had four reading sessions in two consecutive weeks within school hours in a quiet room. They listened to three stories in each session lasting 15 to 20 minutes, including preparation and eye tracker calibration. We randomized the three picture books' sequences using an online randomizer and checked to ensure no repetition. In each session, up to two research assistants were present to instruct the children (“the computer is telling a story, please listen carefully, afterward I will ask you to retell the story”) and operating the eye-tracking machine (e.g., calibration). We presented the books on laptops with the eye trackers mounted below the screen. Once the children started to read, the assistants were not allowed to interrupt their reading. We asked the children to retell the stories right after the first and fourth reading sessions.

## Measures

**Demographic survey.** The Language Exposure Questionnaire (Sun, 2019; Sun, Waschl, & Veera, in press) was used to estimate children’s background, such as the amount of Mandarin and English language exposure and familial socioeconomic status. Also, we investigated children’s experiences with digital books (e.g., whether they have used digital books before the experiment) and home reading history (e.g., the number of English and Mandarin books at home).

**Mandarin and English receptive vocabulary Tests.** The Bilingual Language Assessment Battery (BLAB; Rickard Liow, Sze, & Lee, 2013) is a vocabulary test for Singaporean children’s English and mother tongue language receptive vocabulary sizes. It is similar to the Peabody Picture Vocabulary Test in terms of format (PPVT; Dunn & Dunn, 2007), with 80-trial computerized audio-picture matching tasks to assess single-word receptive vocabulary. Each trial consisted of four pictures, and children were asked to select the picture that corresponded to the heard word. BLAB receptive vocabulary test is reliable in the context of Singapore within the original sample (Cronbach’s *α* = .75-.77) (Rickard Liow et al., 2013) and other studies (e.g., Sun, Ng, O’Brien, & Fritzsche, 2020; Sun et al., 2020).

**Mandarin and English receptive grammar tests.** Children’s English receptive grammar skill was assessed with The Test for Reception of Grammar Version 2 (TROG; Bishop, 2003). Children were exposed to an array of 4 images while they simultaneously heard a spoken sentence, whereafter they were asked to identify the image that matched the sentence. The Mandarin Receptive Grammar Test (MRGT; Bak, 2012) includes 60 trials. The MRGT demonstrated satisfactory external validity (*r*=.64) and internal reliability (Cronbach’s *α*=.75) (Bak, 2012).

**Story retelling.** The static illustrations were visible during the retelling, and the experimenter used a general question (e.g., What happened in this picture?) to prompt the child. If the child did not respond, the experimenter could ask some questions (e.g., what is the character doing?) to elicit story retelling. The child was awarded 0.5 marks for each detail mentioned (Sun et al., 2019). For each page, at least two important details had to be denoted: one detail that was obvious in the static illustration, and one detail that was narrated but not obvious in the static illustration. We calculated a total score for each story retelling after the first and the fourth reading sessions. Five recordings of the storytelling were arbitrarily chosen for inter-rater reliability checks, and the percentage of agreement between the raters was high (*ICC*=.996).

**Visual attention.** We used Tobii X3-120 remote eye trackers to collect eye movement information. Such remote devices allow us to measure children’s visual attention without cumbersome headgear, thus making the reading event more natural with the computer. Post-processing of the eye movement information was used to calculate fixations to or away from the screen. Total (screen) fixation time was recorded for each child for each story at the four readings. Children were seated at 60 cm to 70 cm from the eye tracker for optimal eye movement registration.

In the current study, we were interested in longer fixations (i.e., gaze duration longer than 150 ms), assuming that it takes this amount of time to process complex visual information (Rayner, Smith, Malcolm, & Henderson, 2009). Three participants’ fixation data were removed due to low eye movement registration (i.e., registered eye movements less than 50% of the time), leaving us 89 children’s 1,064 sessions to do the analysis. Dividing the sum of all longer fixation durations by the total duration of the eBook, we obtained a percentage of the total time a child spent on longer fixations on the eBook in each reading session.

Results

## Descriptive Statistics

Children were found to be substantially different from each other in Mandarin (e.g., vocabulary *M* = 37.65, *SD* = 7.77, *range* = 19-56) and English skills (e.g., vocabulary *M* = 44.21, *SD* = 7.77, *range* = 25-64), yielding a fair distribution of bilingual language proficiency. The results of one-way ANOVAs and post-hoc tests revealed that there was no significant difference among children in the three reading conditions in terms of socioeconomic status and language proficiency, indicated by maternal education (*F*(2, 85) = .357, *p* = .701), parental income (*F*(2, 85) = .073, *p* = .929), Mandarin vocabulary (*F*(2, 86) = .305, *p* = .738), Mandarin grammar (*F*(2, 86) = .166, *p* = .847), English vocabulary (*F*(2, 84) = .045, *p* = .956), and English grammar (*F*(2, 84) = 1.538, *p* = .221).

We calculated the proportion of fixation time in which children paid visual attention to the illustration; see Table 1. On average, children’s total fixation time decreased across the replays of the books. In the visual and auditory enhanced condition (i.e., Enhanced1= +motion +sound effects), children could maintain their visual attention for about 60%-70% of their reading time, while in the auditory enhanced condition (i.e., Enhanced2 = -motion + sound effects) and in the static condition (i.e., -motion -sound effects), the percentage decreased to 50% - 60% of the reading time. Despite the general tendency, there were substantial individual differences. Take the first reading of *Little Kangaroo* (i.e., LK1%) as an example. Some children in the visual and auditory enhanced condition only looked at the illustration about 32% of the reading time, while others spent 87% of the book’s time looking at the illustrations.

< Insert Table 1 here>

Like their visual attention, children also demonstrated substantial individual differences in their story retelling. After the first reading session, the retelling scores varied from 0 to 15.5 (*M*=6.48, *SD*=3.61), and their retelling scores after the fourth reading ranged from 1 to 18 (*M*=9.77, *SD*=3.51).

## Bilingual Language Proficiency in Children’s Visual Attention

Children’s Mandarin receptive vocabulary and Mandarin receptive grammar were significantly correlated (*r*=.65, *p*<.001), and so were the two indicators for children’s English proficiency (*r*=.59, *p*<.001). All but one (i.e., English and Mandarin vocabulary) were significantly correlated (*r*= .32-.61). The four language scores were combined using factor analysis, whereafter we performed a median split to create a dichotomous proficiency variable (high vs. low) (Iacobucci, Posavac, Kardes, Schneider, & Popovich, 2015). We fitted a mixed-effects model step-by-step, adding predictors one at a time and removing those that did not contribute significantly to the model fit. After obtaining a final model, we ascertained that the residuals of our model followed a normal distribution. The iterative process created models including the fixed effects of Reading Time (1st, 2nd, 3rd, 4th), Group (Enhanced1, Enhanced2, Static), and Bilingual Proficiency (high, low). Book title and Child ID were included as random effects. To ensure that the random effects were correctly specified, the final model was tested with each random effect, both random effects, and interacting random effects. To compare the AIC across these random effects models, we calculated conditional AICs. The final model that survived the analysis included a three-way interaction of the fixed effects of Reading Time, Group, and Bilingual Proficiency, with separate random effects of Child ID and Book type. We calculated Cohen’s f’s for predictor effect sizes. The traditional interpretation of these suggests the values of 0.10, 0.25, and 0.4 to indicate small, medium, and large effect sizes. For post-hoc contrasts, we calculated Cohen’s d’s.

The ANOVA summary for the final model is in Table 2. There were significant main effects of Reading Time (*p* < .001), where later readings showed lower visual attention, and Group (*p* = .005), where children in the Enhanced1 (+motion + sound effects) digital books condition showed greater visual attention than static (*t*(81) = -3.01, *p* = .010) and enhanced2 (+sound effects) condition (*t*(81) = -2.82, *p* = .017), and a significant three-way interaction effect (*p* = .034), meaning that in the first two sessions, children with higher bilingual proficiency in the Enhanced1 condition demonstrated higher visual attention than their peers with lower bilingual proficiency.

<Insert Table 2 here>

Figure 1 shows the changes in visual attention score over the repetitive readings for each group (i.e., Static vs. enhanced music vs. enhanced music + motion), the decreasing visual attention score across sessions, and the relatively low score of the children with a lower bilingual ability in the first two sessions. Linear contrasts of Reading Time in this interaction were further demonstrated in Table 3. The results revealed significant negative linear trends for higher proficiency bilinguals in both Enhanced1 (+motion +sound effects) (*p* < .001) and Static (*p* = .006) digital book conditions, and a nearly significant trend (*p* = .051) in Enhanced2 condition (+sound effects). Lower proficiency bilinguals showed a negative linear trend for the Static condition only (*p* = .001). There was no significant trend for lower proficiency bilinguals in Enhanced1 (*p* = .882) or in Enhanced2 condition (*p* = .743). This suggests that enhanced digital books maintained visual attention in those with lower language ability. Pairwise linear slope contrasts confirmed this in the Enhanced1 condition, showing a significant difference between the slopes of high and low proficiency bilinguals (*p* = .006).

<Insert Figure 1 here>

<Insert Table 3 here>

Pairwise comparisons between conditions (Table 4) revealed no differences between the Static and Enhanced2 (+sound effects) conditions for either higher or lower proficiency bilinguals (all *p*s > .05). However, the Enhanced1 (+motion +sound) condition showed significantly higher visual attention than the static condition for higher proficiency bilinguals in the first, second, and fourth readings, and for lower proficiency bilinguals in the first, third, and fourth readings (all *p*s < .05). In addition, the Enhanced1 (+motion +sound) condition showed significantly higher visual attention than the Enhanced2 (+sound) condition for high proficiency bilinguals in all four readings (all *p*s < .05), but not for low proficiency bilinguals.

<Insert Table 4 here>

## Children’s Visual Attention and Story Retelling

Mixed effect models adopting the Maximum Likelihood procedure were used to explore the relationship between visual attention and story comprehension. We created separate models for data at the first and fourth readings only (Table 5). The fixed factors were children’s Visual Attention (mean-centered), children’s Bilingual Proficiency (high vs. low), and Group (Enhanced1, Enhanced2, Static), with the random factor Book type. The outcome variables were children’s story retellings after the first, and fourth readings in the two models respectively. The final models included a full interaction of the main effects. The results of the two models indicate that children’s visual attention mattered. More visual attention was significantly and positively correlated with better story retelling at both times (i.e., *p* < .001 after the first reading session; *p* = .026 after the fourth reading session). Children’s bilingual proficiency was also a significant predictor of children’s retelling (i.e., *p* = .022 after the first reading session; *p* < .001 after the fourth reading session).

<Insert Table 5 here>

Discussion

There is growing evidence for the beneficial effects of visual and auditory enhancements added to digital picture books (e.g., Bus et al., 2015; Smeets & Bus, 2015; Sarı et al., 2019; Sun et al., 2019; Takacs & Bus, 2016; Verhallen et al., 2006). We hypothesize that these additions influence visual attention and thereby, meaning making. The goals of the current research were to test 1) the effects of the digital enhancements on children’s visual attention over the repetitive readings and 2) the relationship between children’s visual attention and their story retelling. Given that we focused on children’s visual attention during book reading, we expected the strongest effect from the visually enhanced books. In addition, we explored the effects of children’s bilingual proficiency on children’s visual attention and story retelling.

## Visual Attention and the Impact on Children’s Story Retelling

 The condition with auditory and visual enhancements resulted in greater visual attention (measured as a percentage of total fixation time) across the repeated readings than the condition with only auditory enhancements or no digital enhancements. In other words, the features present in enhanced books, including details in motion and a camera moving through the illustrations, help children process the story. This finding indicates that the visual enhancements, guiding children’s visual attention through the illustrations, could cause deeper processing of the storyline than a static image or a version with just auditory enhancements as indicated by longer eye-fixations. Findings thus are consistent with the theory that visual enhancements help integrate visual information and language (Flack & Horst, 2017; Eng, Tomasic, & Thiessen, 2020; Verhallen & Bus, 2010). Evidence for the effect of the auditory enhancements was not found as there was no significant difference between children’s visual attention between the Enhanced2 condition (-motion +sound effects) and the static condition (-motion -sound effects). As the static condition did not involve a live person, we cannot conclude that the enhancements would be comparable to a live storyteller. A second finding is that visual attention positively correlates with the retelling performance, which corroborates the hypothesis that children who are more attentive during the readings are more successful in reconstructing the storyline. Longer and steadier attention suggests more in-depth processing of the story events (Rayner, 2009), probably leading to better story comprehension. The findings strongly suggest that visual attention is the key driver for the effect of reading condition on better story comprehension. So, we would expect a mediation effect of visual attention on the link between reading condition and story retelling. In the previous study (Sun et al., 2019), a direct effect of reading condition was found on story retelling. Due to the types of statistical models employed in our study, we were unable to test the mediation effect in the current study.

## Bilingual Language Proficiency and Children’s Attention

Both children with high and low bilingual proficiency benefit from visual and auditory enhancements (i.e., Enhanced1 condition). However, this condition was most beneficial for the more advanced group, probably due to their better narrative comprehension. For children with higher bilingual proficiency, digital books with visual and auditory enhancements were more beneficial than the other two conditions in terms of visual attention. However, the outcomes are different for the children with lower bilingual proficiency. The digital books with auditory and visual enhancements (+motion +sound effects) were more beneficial than the static condition (-motion -sound effects), but not the auditory enhanced condition (-motion +sound effects). This result may indicate that combined visual and auditory enhancements are not more beneficial than auditory enhancements when children are less proficient in the language. In other words, our finding suggests that children with a lower language proficiency may particularly benefit from auditory enhancements. This finding aligns with the fact that there are limits to the narrative understanding of the less language-proficient children. They may benefit from auditory enhancements because those primarily target basic understandings of emotions (e.g., irritation elicited by the loudness of the birds' chirping). However, they do not benefit from visual enhancements that often target complex understandings (e.g., mama kangaroo's hopping highlights her exhaustion). Thus, children's narrative comprehension level limits the beneficial effect of the visual guidance in the enhanced books. Our results seem to echo the previous findings on children's visual attention to media content (Anderson, Lorch, Field, & Sanders, 1981; Lorch & Castle, 1997). When the watching material from the TV is out of children's level of understanding, they are more likely to be visually distracted.

Another interesting finding is that the developmental patterns of the lower proficiency children’s visual attention were different in the three reading conditions. In the static reading condition, lower proficiency children's visual attention dropped significantly. In contrast, in the enhanced conditions (Enhanced1 and Enhanced2), these children maintained their relatively high level of visual attention across the four readings. This result indicates that lower proficiency children, in particular, still need support in reconstructing the storyline after one or two readings. The children experience limitations in their narrative comprehension, and due to that, they subject themselves to the guidance of the additional features in the digital books. The enhancements continue influencing their visual attention even after one or two readings. In comparison, attention declined across the readings in all conditions in the higher proficiency group, indicating that they are less in need of support after the first reading.

Limitations and Implications

There are two significant limitations to the study. First, we have only focused on the total fixation time of children’s repetitive readings and have not examined their specific visual attention location. Therefore, it remains unknown how children distributed their attention in different reading modalities and whether digital features help children locate the narrative’s related illustrations faster and assimilate novel information more effectively. Future studies might investigate this research question by assessing both the length and the location of children’s visual attention (e.g., scanning patterns). Researchers may also employ neuroimaging techniques to explore children’s brain activity when they are looking at these different kinds of digital books. Second, we cannot conclude it is the motion feature alone or the interaction between motion and sound effects in the enhanced condition that promotes children’s visual attention. Besides, the role that sound effects play remains unclear. Although sound effects did not lead to children’s better visual attention or story retelling, children with different language profiles seemed to be influenced by this feature differently. Children with higher bilingual proficiency demonstrated lower visual attention than their lower proficiency peers; this leads us to question whether sound effects brought additional cognitive burdens to these higher proficiency children. Another possibility is that sound effects may only be effective for lower proficiency children through better engagement and learning motivation. Future studies may unravel the features of the enhanced condition to explain children’s longer total fixation. A well-designed experiment with larger sample size and a follow-up interview on sound effects may reveal 1) potentially differential effects of sound effects on higher and lower bilingual proficiency children’s reading process, and 2) the cognitive and affective reasons that result in such differential effects. Despite these limitations, the current findings contribute to the practice of (children’s) digital books reading.

Our study suggests that well designed, visually enhanced digital books support processing the storyline, regardless of proficiency level. The enhancements included in our digital books improved children’s ability to process the narration and illustrations and make meaning. Compared to the static digital books, enhanced digital books appear to be useful, as the motion features would probably enhance multimedia learning’s primary mechanism. The lower proficiency group preserves a rather high level of visual attention across sessions indicating that they are more inclined to invest in processing the story if the book is enhanced with technology. In comparison, the static book did not convey any additional benefits to lower proficiency learners during the story replays, probably because they miss the support that helps make meaning. To summarize, we can conclude that well-designed digital books for the growing group of bilingual children can be a very helpful tool in supporting their language development. High-quality picture books with digital enhancements are a good supplement for the new generation of child bilingual’s language exposure.

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Tables

**Table 1**

*Children’s total fixation time (raw score) and percentage out of the whole reading length (visual attention score in proportion) across the four readings for each storybook*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Raw | *Group* | *M* | *SD* | *range* | *Visual Attention* | *M* | *SD* | *range* |
| LK1 | Enhanced1 | 181.25 | 30.86 | 79.4-212.64 | LK1 (%) | 0.74 | 0.13 | 0.32-0.87 |
|  | Enhanced2 | 144.78 | 37.85 | 25.05-188.56 |  | 0.58 | 0.15 | 0.1-0.76 |
|  | Static  | 141.41 | 39.13 | 36.02-205.52 |  | 0.57 | 0.16 | 0.15-0.83 |
| LK2 | Enhanced1 | 169.62 | 41.44 | 43.72-214.93 | LK2 (%) | 0.69 | 0.17 | 0.18-0.88 |
|  | Enhanced2 | 133.77 | 48.61 | 16.07-199.51 |  | 0.54 | 0.2 | 0.06-0.8 |
|  | Static  | 141.24 | 36.02 | 50.46-187.15 |  | 0.57 | 0.15 | 0.20-0.76 |
| LK3 | Enhanced1 | 168.56 | 32.36 | 97.38-204.6 | LK3 (%) | 0.69 | 0.13 | 0.40-0.84 |
|  | Enhanced2 | 143.56 | 36.57 | 17.75-198.92 |  | 0.58 | 0.15 | 0.07-0.8 |
|  | Static  | 131.94 | 35.96 | 42.63-192.15 |  | 0.53 | 0.15 | 0.17-0.78 |
| LK4 | Enhanced1 | 163.12 | 41.66 | 70.1-208.16 | LK4 (%) | 0.67 | 0.17 | 0.29-0.85 |
|  | Enhanced2 | 136.46 | 43.92 | 40.36-196.16 |  | 0.55 | 0.18 | 0.16-0.79 |
|  | Static  | 125.02 | 35.17 | 49.42-185.52 |  | 0.51 | 0.14 | 0.20-0.75 |
| CC1 | Enhanced1 | 177.22 | 35.81 | 63.1-215.97 | CC1 (%) | 0.71 | 0.14 | 0.25-0.86 |
|  | Enhanced2 | 162.44 | 31.96 | 68.92-204.15 |  | 0.63 | 0.12 | 0.27-0.79 |
|  | Static  | 158.58 | 37.81 | 58.29-212.03 |  | 0.64 | 0.15 | 0.24-0.85 |
| CC2 | Enhanced1 | 167.31 | 46.26 | 32.32-208.66 | CC2 (%) | 0.67 | 0.19 | 0.13-0.83 |
|  | Enhanced2 | 151.81 | 41.43 | 43.48-197.15 |  | 0.59 | 0.16 | 0.17-0.76 |
|  | Static  | 159.13 | 33.94 | 80.76-199.37 |  | 0.64 | 0.14 | 0.33-0.80 |
| CC3 | Enhanced1 | 174.82 | 33.38 | 84.13-208.97 | CC3 (%) | 0.70 | 0.13 | 0.34-0.84 |
|  | Enhanced2 | 160.46 | 31.77 | 37.04-199.44 |  | 0.62 | 0.12 | 0.14-0.77 |
|  | Static  | 154.43 | 39.05 | 61.55-206.05 |  | 0.62 | 0.16 | 0.25-0.83 |
| CC4 | Enhanced1 | 174.76 | 36.24 | 77.67-224.24 | CC4 (%) | 0.70 | 0.14 | 0.31-0.90 |
|  | Enhanced2 | 154.80 | 36.53 | 69.61-202.92 |  | 0.60 | 0.14 | 0.27-0.78 |
|  | Static  | 149.07 | 35.17 | 58.55-187.25 |  | 0.60 | 0.14 | 0.24-0.76 |
| CWG1 | Enhanced1 | 186.94 | 32.80 | 92.23-224.21 | CWG1 (%) | 0.70 | 0.12 | 0.35-0.84 |
|  | Enhanced2 | 168.16 | 35.46 | 106.61-226.61 |  | 0.63 | 0.13 | 0.4-0.84 |
|  | Static  | 164.38 | 44.24 | 56.99-233.06 |  | 0.61 | 0.16 | 0.21-0.87 |
| CWG2 | Enhanced1 | 178.00 | 47.78 | 34-215.32 | CWG2 (%) | 0.67 | 0.18 | 0.13-0.81 |
|  | Enhanced2 | 157.26 | 48.27 | 47.03-216.45 |  | 0.58 | 0.18 | 0.17-0.8 |
|  | Static  | 156.43 | 46.69 | 34.59-223.93 |  | 0.58 | 0.17 | 0.13-0.83 |
| CWG3 | Enhanced1 | 171.26 | 48.83 | 39.4-224.38 | CWG3 (%) | 0.64 | 0.18 | 0.15-0.84 |
|  | Enhanced2 | 160.94  | 40.18 | 38.65-224.84 |  | 0.60 | 0.15 | 0.14-0.84 |
|  | Static  | 158.01 | 44.74 | 64.83-228.33 |  | 0.59 | 0.17 | 0.24-0.85 |
| CWG4 | Enhanced1 | 176.73 | 38.91 | 95.89-230.79 | CWG4 (%) | 0.66 | 0.15 | 0.36-0.87 |
|  | Enhanced2 | 160.64 | 43.14 | 62.08-227.38 |  | 0.60 | 0.16 | 0.23-0.85 |
|  | Static | 145.83 | 47.12 | 69.12-222.48 |  | 0.54 | 0.18 | 0.26-0.83 |

*Note.* LK= the book “Little Kangaroo”, CC = the book “Copycat”, and CWG = the book “Cycling with Grandpa”. Enhanced1 condition = digital books with visual and auditory enhancements, Enhanced2 condition = digital books with only auditory enhancements, and Static condition = digital books with neither visual nor auditory enhancements

**Table 2.**

*ANOVA summary for visual attention score in low vs high bilinguals*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Effect | *Sum Sq* | *Mean Sq* | *F* | *df* | *df(E)* | *p* | *f* |
| Reading Time | 0.26 | 0.09 | 9.91 | 3 | 931.92 | <0.001 | \*\*\* | 0.18 |
| Group | 0.10 | 0.05 | 5.78 | 2 | 80.91 | 0.005 | \*\* | 0.38 |
| Bilingual Proficiency | 0.00 | 0.00 | 0.30 | 1 | 80.91 | 0.588 |  | 0.06 |
| Reading Time x Group | 0.10 | 0.02 | 1.95 | 6 | 931.92 | 0.070 |  | 0.11 |
| Reading Time x Bilingual Proficiency | 0.05 | 0.02 | 2.00 | 3 | 931.92 | 0.112 |  | 0.08 |
| Group x Bilingual Proficiency | 0.02 | 0.01 | 1.03 | 2 | 80.91 | 0.361 |  | 0.16 |
| Reading Time x Group x Bilingual Proficiency | 0.12 | 0.02 | 2.28 | 6 | 931.92 | 0.034 | \* | 0.12 |

**Table 3.**

*Linear contrasts for the effect of Reading Time separately for Group and Bilingual Proficiency*

|  |  |  |
| --- | --- | --- |
|  |  |  |
| Group | Bilingual Proficiency | *Estimate* | *SE* | *df* | *t* | *p* | *d* |
| Enhanced1 | Low | -0.01 | 0.06 | 932.00 | -0.15 | .882 |  | -0.01 |
|  | High | -0.25 | 0.06 | 932.01 | -4.01 | < .001 | \*\*\* | -0.26 |
| Enhanced2 | Low | 0.02 | 0.07 | 932.10 | 0.33 | .743 |  | 0.02 |
|  | High | -0.12 | 0.07 | 932.00 | -1.95 | .051 | - | -0.13 |
| Static | Low | -0.20 | 0.06 | 932.00 | -3.23 | .001 | \*\* | -0.21 |
|  | High | -0.19 | 0.07 | 932.01 | -2.75 | .006 | \*\* | -0.18 |

*Note.* Enhanced1 condition = digital books with visual and auditory enhancements, Enhanced2 condition = digital books with only auditory enhancements, and Static condition = digital books with neither visual nor auditory enhancements

**Table 4.**

*Pairwise comparisons between conditions in each reading*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Bilingual proficiency | Reading Time | Comparison | *Estimate* | *SE* | *df* | *t* | *p* | *d* |
| Low | 1 | Enhanced1- Enhanced2 | 0.06 | 0.05 | 103 | 1.10 | .275 | 0.22 |
|  |  | Enhanced1- Static | 0.10 | 0.05 | 103 | 1.99 | .050 \* | 0.39 |
|  |  | Enhanced2 – Static | 0.04 | 0.05 | 103 | 0.74 | .459 | 0.15 |
|  | 2 | Enhanced1- Enhanced2 | 0.04 | 0.05 | 103 | 0.79 | .429 | 0.16 |
|  |  | Enhanced1- Static | 0.03 | 0.05 | 104 | 0.70 | .488 | 0.14 |
|  |  | Enhanced2 – Static | -0.01 | 0.05 | 104 | -0.15 | .882 | -0.03 |
|  | 3 | Enhanced1- Enhanced2 | 0.05 | 0.05 | 103 | 1.04 | .303 | 0.2 |
|  |  | Enhanced1- Static | 0.11 | 0.05 | 104 | 2.26 | .026 \* | 0.44 |
|  |  | Enhanced2 – Static | 0.06 | 0.05 | 104 | 1.06 | .293 | 0.21 |
|  | 4 | Enhanced1- Enhanced2 | 0.04 | 0.05 | 104 | 0.81 | .419 | 0.16 |
|  |  | Enhanced1- Static | 0.13 | 0.05 | 103 | 2.75 | .007 \*\* | 0.54 |
|  |  | Enhanced2 – Static | 0.09 | 0.05 | 104 | 1.73 | .087 | 0.34 |
| High | 1 | Enhanced1- Enhanced2 | 0.15 | 0.05 | 103 | 3.13 | .002 \*\* | 0.62 |
|  |  | Enhanced1- Static | 0.12 | 0.05 | 103 | 2.19 | .031 \* | 0.43 |
|  |  | Enhanced2 – Static | -0.04 | 0.05 | 103 | -0.73 | .468 | -0.14 |
|  | 2 | Enhanced1- Enhanced2 | 0.18 | 0.05 | 104 | 3.58 | <.001 \*\*\* | 0.7 |
|  |  | Enhanced1- Static | 0.13 | 0.05 | 104 | 2.43 | .017 \* | 0.48 |
|  |  | Enhanced2 – Static | -0.05 | 0.05 | 103 | -0.90 | .369 | -0.18 |
|  | 3 | Enhanced1- Enhanced2 | 0.10 | 0.05 | 103 | 1.99 | .049 \* | 0.39 |
|  |  | Enhanced1- Static | 0.08 | 0.05 | 104 | 1.54 | .127 | 0.3 |
|  |  | Enhanced2 – Static | -0.02 | 0.05 | 104 | -0.32 | .754 | -0.06 |
|  | 4 | Enhanced1- Enhanced2 | 0.14 | 0.05 | 103 | 2.77 | .007 \*\* | 0.54 |
|  |  | Enhanced1- Static | 0.11 | 0.05 | 103 | 2.12 | .036 \* | 0.42 |
|  |  | Enhanced2 – Static | -0.02 | 0.05 | 103 | -0.45 | .651 | -0.09 |

*Note.* Enhanced1 condition = digital books with visual and auditory enhancements, Enhanced2 condition = digital books with only auditory enhancements, and Static condition = digital books with neither visual nor auditory enhancements

**T****able 5.**

*ANOVA summary for the Impact of Children’s Visual Attention, Bilingual Proficiency, and Reading Condition on Story Retelling after the First and the Fourth Readings (Q2)*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Effect | *Sum Sq* | *Mean Sq* | *F* | *df* | *df(E)* | *p* | *f* |
| First Reading |  |  |  |  |  |  |  |
|  | Visual Attention | 180.89 | 180.89 | 17.94 | 1 | 258.14 | < .001 \*\*\* | 0.26 |
|  | Bilingual Proficiency  | 53.76 | 53.76 | 5.33 | 1 | 258.11 | .022 \* | 0.14 |
|  | Group | 49.69 | 24.85 | 2.46 | 2 | 258.09 | .087  | 0.14 |
|  | Attention x Bilingual Proficiency | 6.20 | 6.20 | 0.61 | 1 | 258.23 | .434 | 0.05 |
|  | Attention x Group | 28.53 | 14.27 | 1.41 | 2 | 259.11 | .245 | 0.10 |
|  | Bilingual Proficiency x Group | 58.99 | 29.50 | 2.92 | 2 | 258.15 | .055 - | 0.15 |
|  | Attention x Bilingual Proficiency x Group | 59.85 | 29.93 | 2.97 | 2 | 258.15 | .053 - | 0.15 |
| Fourth Reading |  |  |  |  |  |  |  |
|  | Visual Attention | 48.06 | 48.06 | 5.05 | 1 | 258.96 | .026 \* | 0.14 |
|  | Bilingual Proficiency  | 122.27 | 122.27 | 12.84 | 1 | 258.04 | < .001 \*\*\* | 0.22 |
|  | Group | 2.78 | 1.39 | 0.15 | 2 | 258.05 | .864 | 0.03 |
|  | Attention x Bilingual Proficiency | 1.43 | 1.43 | 0.15 | 1 | 258.01 | .698 | 0.02 |
|  | Attention x Group | 8.29 | 4.15 | 0.44 | 2 | 258.43 | .648 | 0.06 |
|  | Bilingual Proficiency x Group | 24.59 | 12.29 | 1.29 | 2 | 258.02 | .277 | 0.10 |
|  | Attention x Bilingual Proficiency x Group | 57.05 | 28.53 | 3.00 | 2 | 258.06 | .052 - | 0.15 |

Figures

**Figure 1**

*Children’s Attention in Relation to Bilingual Language Proficiency and Reading Conditions over Repetitive Readings*



*Note.* Red and solid lines refer to low bilingual language proficiency, while blue and dashed lines refer to high proficiency. Ribbons indicate ± Standard Error of the Mean.