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Research article

Executive attention modulates the facilitating effect of electronic storybooks on information encoding in preschoolers

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ABSTRACT

Interactive features and multimedia elements in electronic storybooks might enhance knowledge acquisition in children due to the playful learning experience they provide. However, to date, there is no systematic research on the long-term efficacy of storybooks, and the individual cognitive factors that influence information processing when using these apps. Therefore, in Experiment 1, we focused on long-term improvements. Children (M = 5.55 years, SD = 0.51, N = 33) were divided into an Interactive App group (N = 16) and a Print Book group (N = 17), then they were exposed to a story. Their recall performance was measured immediately after the exposure and three weeks later. In Experiment 2, we focused on individual differences in cognitive factors (working memory and sustained attention). Children (M = 5.56 years, SD = 0.62, N = 32) were exposed to three stories with interactive, multimedia-only elements and an audio-only condition. Caregivers were asked to fill out the ADHD Rating Scale-IV regarding each child. According to our results, in Experiment 1, children in the Interactive App group performed better compared to the Print Book group and this improvement persisted over time. In Experiment 2, we replicated the results of Experiment 1, however, children with poorer sustained attentional abilities performed worse in multimedia and interactive conditions compared to the audio-only condition. Our results indicate that electronic storybooks can facilitate learning because they enhance encoding efficacy. However, the benefit is only evident in children with good attentional control abilities. Our results guide parents and educators on how to choose and design age-appropriate applications for learning.

1. General introduction

A wide range of applications with supposedly educational benefits is available with the purpose to help young children's knowledge acquisition. Currently, the most popular applications available on Google Play are labeled as educational, with 60% of them targeting preschoolers [1]. For educational applications, the best examples include electronic storybook applications, that use multimedia elements and interactive features to adapt traditional storytelling for touchscreen devices [2]. Electronic storybooks are user-friendly and easy to use even for pre-readers which makes them increasingly popular with parents and teachers [3]. Although electronic storybooks provide some benefits for emergent literacy and general knowledge acquisition the results are controversial [4]. In

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addition, applications with an educational label do not always deliver the educational outcome that they promised [5]. Empirical studies are therefore crucial to guide teachers and parents to find applications designed for effective knowledge acquisition [6,7].

2. Experiment 1

2.1. Introduction

The popularity of electronic storybooks is not surprising considering that embedded multimedia elements and interactive features are excellent tools for playful learning. Multimedia elements – including narration, animated illustrations, background music, sound effects, and camera effects – can support general knowledge acquisition in many ways [4]. Animated illustrations are effective tools for guiding attention toward relevant information on the screen [8]. Supplemented by sound effects and background music, they have further potential to promote understanding of abstract words [4] and recognition of emotions and mental states [9,10]. Using interactive features activated through the touchscreen can provide further benefits. The purpose of interactive features is to actively involve the user in the presented story through embedded activities strongly related to the plot [2]. For example, helping a cartoon figure make pancakes by putting all the ingredients into a bowl using the touchscreen (see Berry and Dolly – Summer Tale: Pancake Party; ONCE Digital Arts Ltd). Learning, accompanied by relevant physical activities can enhance understanding and recalling [11-13]. Recent studies in the field of embodied learning also emphasize the importance of integrating physical movements into the learning process [14-16]. Overall, children seem to learn easier through interactive applications with embedded multimedia and can transfer the acquired knowledge to the physical world [17–20].

There are an increasing number of studies regarding the potential benefits of electronic storybooks on vocabulary or story comprehension (see Refs. [3,8,21,22]), however still little is known about the long-term advantages. Furenes and colleagues (2021) emphasize that most of the studies approach electronic storybooks in the context of learning, yet the number of longitudinal studies is extremely low. Furthermore, the exact processes behind the benefits are not well-understood. For instance, we do not know whether the alleged benefits of using electronic storybooks come from more efficient coding or mitigated forgetting. In the framework of the *cognitive theory of multimedia learning* [23] it may be assumed that the multimodal communication of information (multimedia elements) and the physical activity through interactive features have an immediate effect on coding new information. However, we still do not know for certain that the information gained by electronic storybooks will be better stored in long-term memory [24,25]. Increasing the number of longitudinal studies in this field is extremely important, only studies with such a design can tell how effectively these applications can support learning outcomes in the long term.

Thus, in Experiment 1, we sought to investigate the *long-term effects* of electronic storybooks on recall performance in preschoolers. We measured long-term outcomes after three weeks, as it can be assumed after this period, we would assess information consolidated in the long-term memory [26]. We selected electronic storybooks containing interactive and multimedia elements relevant to the story that facilitate engagement in the plot. This is important to highlight as the variety of interactive features and the lack of operationalization can make it more difficult to interpret the data regarding interactive features [27]. The multimedia elements and interactive features in the selected electronic storybooks were not just relevant, but also simultaneously presented with the narration. This is one of the key features of avoiding cognitive load and enhancing information processing [28–31]. Because of the huge age-related differences in the maturation of executive functions [32,33] in our study we targeted a narrow age spectrum between 5 and 6 years. As was pointed out [24], to date, there is little known about the long-term advantages of electronic storybooks in the context of learning. Thus, in Experiment 1, we aimed to test a possible long-term improvement after using an electronic storybook with multimedia elements and interactive features. We hypothesized that children using an interactive electronic storybook will recall more accurate details than children who heard the experimenter read aloud the same story. We predict that improvement will be observed both immediately after the exposure and three weeks later.

2.2. Materials and methods

In our first experiment, we used a design similar to the study of [34]. They used traditional and electronic storybooks to present stories to children and then asked short questions immediately following the exposure to assess their recall performance. In addition to this, besides the short questions, we also asked the children to retell the story. Both methods are well-established in the literature on electronic storybooks [24]. Furthermore, we also did a follow-up measurement three weeks after the first assessment to investigate the persistence of changes in recall performance. Such follow-up tests are necessary because they show whether the improvement is due to better encoding or a more efficient retrieval of the information.

2.2.1. Sample

We recruited a total of 33 children (14 girls) between the ages of 5 and 6 ($M = 5.55$; $SD = 0.506$). The sample size for this experiment was determined by computing estimated statistical power. We conducted an a priori power analysis using G*Power software [35] to test for repeated measures GLM (within-between interaction) with 4 (2×2) correlating repeated measures ($r = 0.45$). The analysis, based on previous studies [3,8] indicated a required total sample size of 16 ($f = 0.40$, $1 - \beta = 0.80$). We recruited children through kindergartens. We contacted the principals of the kindergartens and gave them a detailed description of our study. If the principal agreed to participate, we asked for contact with the kindergarten teachers. If a teacher also agreed to help us, we asked them to hand out informed consent forms to the parents of each child in their group. Although the parents of 47 children signed the consent form, a total of 14 children were excluded from the final sample. Ten of them had previous knowledge about the story used in the experiment, three of them could not be reached for the follow-up session and one child failed to follow the instructions. All the participants were typically developing children, and no neurological or other disorders were reported by their parents; 75% of the children use smartphones or tablets at least weekly, and the rest of them had no earlier experiences with touchscreen devices. All children involved in our study were prereaders.

Children were randomly assigned into two groups: an interactive application group ($N = 16$) and a print book group ($N = 17$). Members of the interactive application group were introduced to a story by an interactive storybook application, while the print book group listened to it traditionally. Data were collected individually in both groups. The study was approved by the local ethics committee (2020-108) and was carried out under the Declaration of Helsinki. All children have verbally agreed to participate.

2.2.2. Instruments

2.2.2.1. The storybook. We selected a Hungarian folktale (The Little Rooster and His Diamond Halfpenny) for the exposure. The tale is commercially available both in paper book format and as an interactive storybook. Each version is the same length and contains 468 words. It presents a simple story about a little rooster who finds a diamond halfpenny. The greedy Sultan takes the diamond halfpenny from the rooster therefore the rooster must outwit the Sultan to get the halfpenny back. The *interactive storybook application* we used in this study was developed by TechLab of Moholy-Nagy University of Art and Design (http://techlab.mome.hu/). The interactive storybook has 10 pages and each of them contains 46.8 words and 2 interactions on average. Read-aloud function and sound effects (like the sound of the bees or birds singing) are included as well. The interactive storybook was presented using a Lenovo TAB2 A10-30 10" touchscreen device. The *print book version* was read aloud by the experimenter from a Hungarian folktale collection by Laszlo Arany (1995). The print book version was presented without any illustration. The texts of the electronic storybook and the print book version were identical.

2.2.2.2. Recall performance. We used two methods to measure recall performance. First, children were asked to retell the story (henceforth named *retelling*) as best as they could remember; then they were asked to answer nine questions (henceforth named *short Q&A*) related to characters and the plot (e.g., "What did the little rooster find?" and "Where did the little rooster find it?"). We always started with the retellings to avoid the potential influence of the short Q&A on the number of recalled words. Retellings were evaluated by counting the number of recalled words from the story. The children recalled 8 ($SD = 7.16$) words on average; the minimum number of words was 0, and the maximum was 25. The answers to the short Q&A were rated using a three-point scale between 0 and 2. Wrong answers meant 0 points, correct but incomplete answers meant 1 point, and correct answers meant 2 points. Children could achieve a maximum of 18 points by answering all 9 questions correctly. All answers were scored by two independent scorers. One of the scorers was the first author of this paper, the other one was a faculty member of the University and blind to the aim of the study. The achieved points ranged from 1 to 18 points ($M = 9.22$; $SD = 4.15$). The agreements between the scorers were tested using Kendall's coefficient of concordance. Inter-rater reliability was 0.895; with a 77% agreement ($p < .001$) that indicated substantial correspondence between the scorers.

2.2.2.3. Working memory (WM) capacity. WM capacity was measured using the Hungarian version of the *Listening Span Task* [36]. Children were asked to listen carefully to a few sets of sentences then decide if the statements are true or false then repeat the last word of each sentence. The number of sentences increases by one in each set. The first set contains two sentences. If the child cannot correctly recall the last word of all the sentences in the same set the examiner stops there and switch to the next block. The task consists of three blocks. Children received points separately in each block which was equal to the number of sentences in that set where they could correctly recall the last words of each sentence. Finally, the WM capacity was indicated by the mean values of the points received in the three blocks. The *listening Span Task* can be used between the ages of 4–89 years; therefore, the task is suitable for the young sample of the study. The results of the Listening Span Task were used as an indicator of the children's WM capacity. The achieved scores by the children ranged from 0 to 2.33 points. Higher scores indicate better performance.

2.2.3. Procedure

We used a between-subjects design; thus, children were randomly assigned into two groups. Members of the interactive application group were introduced to the story by an interactive storybook application on a Lenovo tablet (with a 10-inch screen). In this group, children could freely explore the application, while the story was presented by the read-aloud function. In the print book group, the story was read aloud by the first author without any further illustration. Immediately after the exposure, the children retold the story, and then answer the short Q&As (Time 1). The answers of the children were recorded for later analysis.

The study was conducted in a spare, quiet room at the preschool. The children participated individually, only the experimenter was present during the story exposure and the data collection. The experimenter established rapport through a small conversation with the child, then explained what would happen during the task. The child was informed that participation is voluntary and there are no negative consequences of withdrawal from the study. Participation required the verbal consent of the child. Children were also asked if they were familiar with the story. If they answered yes, we asked them to recall as many elements from the story as they could. Those with previous knowledge were excluded from the data analysis. Recalling correctly at least one element served as an exclusion criterion.

Three weeks after the story exposure and the first measurement of the recall performance, a second data collection was conducted (Time 2). Children were, again, asked to retell the story, and then answer the same nine questions, similarly to the first time. The story

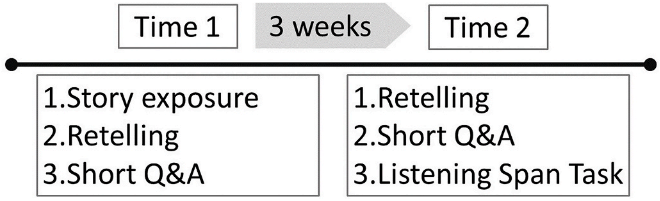

Fig. 1. The experimental design of Experiment 1. In the figure, the exact measurements are shown belonging to the first (Time 1) and second (Time 2) data collection. Three weeks passed between Time 1 and Time 2. At Time 1 children listened to a story or used an electronic storybook with interactive features, then we asked them to retell the story and complete a short questionnaire (Short Q&A) with open-ended questions regarding the story. At Time 2, the children retold the story and completed the Short Q&A once again. They also completed the Listening Span Task as a measurement of working memory capacity.

was not repeated during the second meeting. Children also completed the Listening Span Task at this phase of the study. All children received a small reward for their participation. Participation lasted about 30 min in Time 1 and 15 min in Time 2. See the full experimental design in Fig. 1.

2.2.4. Data analysis

Statistical analyses were performed using the JAMOVI Statistics Programme (Version 1.2.27.0 for Windows). Outliers (number of recalled words more than 2 SD from the mean) were excluded, approximately 9% of all the collected data.

First, we analyzed the data from the retellings, then the ratings of the short answers to the questions. In both cases, we performed a General Linear Model (GLM) analysis with the number of recalled words (retelling) or total points (short Q&A) as the dependent variables, respectively. The book format (interactive storybook or print book) was the between-subject factor and the time of the measurement of the recall performance was entered as a within-subject factor. We used WM capacity (results of the Listening Span Task) as the covariate variable.

2.3. Results

Regarding the *number of recalled words (retellings)*, the two groups did not differ (F (1,23) = 1.42, p = .246). Neither the main effect of the time of the measurement (F (1,23) = 1.33, p = .260) nor the interaction between the time of the retelling and the book format was significant (F (1,23) = 0.02, p = .901). WM capacity had no significant effect on the performance (F (1,23) = 1.22, p = .281). Means and standard deviations are reported in Table 1.

Regarding the *ratings received for the short Q&A*, we found a significant difference between the two groups (F (1,29) = 4.65, p = .039; $\eta p^2 = 0.138$). The members of the interactive application group reached higher scores on the nine questions compared to those of the print book group. As expected, we found a significant main effect of time (F (1,29) = 6.404, p = .017, $\eta p^2 = 0.181$), as the performance dropped over time, and children of both groups recalled fewer details about the story in Time 2 compared to Time 1. The interaction (F (1,29) = 0.369, p = .548) and the effect of WM capacity were nonsignificant (F (1,29) = 0.29, p = .598). The two groups did not differ regarding the scores gained on the Listening Span Task (t (31) = −.207; p = .837). Means and standard deviations are reported in Table 1. Distributions of the data regarding recall performance on the short Q&A are reported in Fig. 2. The Benjamini–Hochberg false discovery rate procedure was used to correct for multiple comparisons [37-39].

Table 1
Means and standard deviations of the Listening Span Task and recall performance in terms of the number of recalled words (Retelling) and points received to the short answers (short Q&A), separately for Time 1 (immediately after hearing the story) and Time 2 (three weeks later), Interactive application and Print book format.

Task	Phase	Group	Mean	SD
Retelling	Time 1	Interactive app	9.07	7.69
		Print book	6.08	6.49
	Time 2	Interactive app	8.80	8.25
		Print book	4.85	5.94
Short Q&A	Time 1	Interactive app	10.9	4.03
		Print book	7.76	3.78
	Time 2	Interactive app	9.27	3.28
		Print book	6.82	4.56
Listening Span Task		Interactive app	.586	.794
		Print book	.643	.775

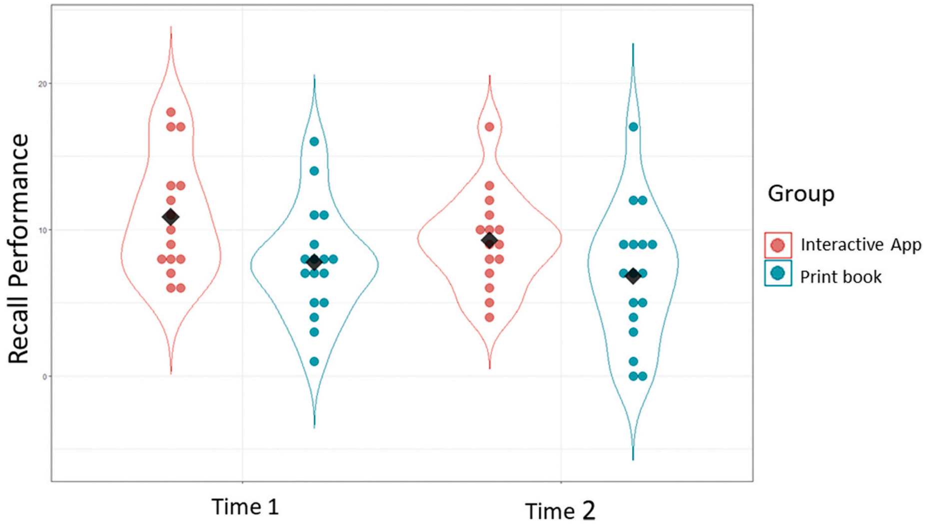

Fig. 2. The distributions and means of recall performance on the Short Q&A (number of correct answers) right after the story exposure (Time 1) and three weeks later (Time 2), separately for the interactive application group and the print book group. Black diamonds show the mean scores, dots represent the actual score of participants.

2.4. Discussion

In Experiment 1 we aimed to test the possible long-term benefits of using an electronic storybook. Children in the *interactive application group* performed better than those in the *print book group* considering the result of the short Q&A. This is in line with previous studies showing the potential benefits of electronic storybooks on story comprehension [3,8,40] and supports the idea that young children may benefit from interactive features and multimedia elements in knowledge acquisition. However, we did not find a significant difference in the efficiency of retelling between the *interactive application* and the *print book group*. Although retelling is a frequently used method to measure recall performance [24], considering the less efficient narrative competencies of preschoolers [41] reconstruction of the story might be more challenging than answering short questions. Since retelling rather reflects the narrative competencies than recall performance [42], in our second study we used exclusively the short Q&As.

The interaction between time and book format was nonsignificant, that is, children in the *interactive app group* performed better than those in the *print book group* even after three weeks – since the initial group difference did not diminish in the short Q&A. Thus, we may assume that the improvement in recall performance results from the more efficient encoding of new information rather than better memory consolidation. Hence, we decided to drop the follow-up measurements and focus more on encoding in Experiment 2. Also, considering these results the next question to address is whether individual cognitive factors (for instance WM capacity or attention) influence the encoding of new information. Previous studies showed the importance of individual differences in attention and WM capacity in the success of encoding new information and integrating information from multiple sources [43]. However, here, we did not find evidence of the influence of WM capacity. Although the Listening Span Task is a validated tool to measure WM capacity from 4 years of age, in the present sample we found that it did not differentiate between participants. This is because the task and instructions were hard to understand and follow. Thus, in Experiment 2, we used a different, more widely used task to assess the WM capacity of the children.

The characteristics of multimedia elements and interactive features can also affect the efficiency of information processing through electronic storybooks. Interactive features compared to multimedia elements might be more demanding for the limited cognitive capacities and immature executive functions of preschoolers [28,44]. For testing this, in our second experiment, we introduced a multimedia-only application condition besides the interactive and audio conditions.

3. Experiment 2

3.1. Introduction

Although Experiment 1 in line with many earlier studies proved that electronic storybooks could facilitate general knowledge acquisition, benefits are not always observed [45]. An important, yet often overlooked factor in understanding the influence of electronic storybooks on knowledge acquisition is the current developmental state of executive functions [46,47]. During the pre-school years (and even later) the maturation of executive functions, such as working memory (WM) capacity and the executive attention network, is still ongoing, thus preschoolers are characterized by high distractibility and a short attention span [48–50]. Since the maturation of the executive attention network is a key to top-down attention and maintaining attentional focus in the presence of distractors, focusing on relevant information may be particularly difficult for those with less efficient attentional mechanisms [49].

Besides executive attention, WM capacity might also have a great role in the inhibition of distractors and focusing attention. Individuals with higher WM capacity may show more efficient learning in a digital environment with distractors [51]. Individual differences in the maturity of executive functions may very well explain why the advantages of electronic storybooks are not always reflected in performance. In a multimedia learning setting where multiple information sources are presented simultaneously focusing on and allocating attention toward relevant information might be difficult for those with less effective attentional mechanisms and WM capacity. Later on, this might result in reduced quality of information processing and worse recall performance. However, there is only a little evidence supporting these claims, and a recent systematic review [52] calls for further research in this area.

Processing information while using interactive features might be particularly difficult, as they often require switching between tasks and sharing attention [4]. Since interactive elements are controlled by the user, there could be a time lag between interactive features and upcoming information. This time lag makes it more challenging to integrate information from different modalities which may decrease the quality of information processing [28,53]. Compared with interactive features, multimedia elements play automatically and simultaneously with the narration, thus, there is a decreased risk of interference between information coming from different modalities [31]. A few studies (e.g. Refs. [29,54,55]) have also reported that the academic performance of children with a lower level of attention regulation improved after using multimedia-only subject materials. Presumably, multimedia elements improve academic performance by orienting attention toward relevant information, while using digital devices can maintain motivation [8,17]. Although multimedia elements were shown to be useful even for those with less efficient executive functions, how interactive elements affect processing has not yet been explored. Nevertheless, it can be assumed that interactive features can interfere with information processing by providing a source of distraction and reducing temporal contiguity.

The aim of Experiment 2, therefore, was to explore how individual differences in the maturation of executive functions might influence the benefits of using electronic storybooks. Understanding how individual differences in executive functions affect the processing of multimedia elements and interactive features might guide developers, educators, and parents to create an appropriate digital environment for learning while accounting for the individual needs of the children. Therefore, in Experiment 2, we investigated how individual differences in attentional performance and working-memory capacity can influence encoding new information by using both interactive and multimedia-only electronic storybooks. We used an interactive storybook condition (same as in Experiment 1) and a multimedia-only electronic storybook (without interactive features) condition to differentiate between the effect of multimedia elements and interactive features on recall performance. We hypothesized that using interactive features will be more demanding for those with less matured attentional mechanisms and a smaller WM capacity, which will result in poorer recall performance in the interactive condition. However, we expected that in the multimedia-only condition the improvement in recall performance will not be affected by individual differences in cognitive factors.

3.2. Materials and methods

The procedure was highly similar to Experiment 1. The four key differences were that (1) we used a within-subject design, in which each child participated in three conditions. Children participated in three conditions because (2) we included an additional, multimedia (henceforth named multimedia-only, without interactive features) storybook condition to separate the effect of multimedia and interactive features on recall performance. Further, (3) we only used the short Q&A to measure recall performance since we did not find any differences in retellings across conditions in Experiment 1. Furthermore, (4) we decided not to conduct a follow-up test and move the focus of Experiment 2 to explore the differences between conditions. We decided to leave out the follow-up tests, because in Experiment 1 there was no significant interaction between time and book format, suggesting that differences between conditions can be measured immediately after the exposure.

3.2.1. Sample

We recruited a total of 32 (16 girls) children between 5 and 6 years of age ($M = 5.56$; $SD = 0.619$). We conducted an a priori power analysis using G*Power software [35] to test for repeated measures GLM (within factors) with 3 (1×3) correlating repeated measures ($r = 0.45$). The analysis, based on Experiment 1 indicated a required total sample size of 13 ($f = 0.40$, $1 - \beta = 0.80$). We recruited children through kindergartens. We contacted the principals of the kindergartens and gave them a detailed description of our study. If the principal agreed to participate, we asked for contact with the kindergarten teachers. If a teacher also agreed to help us, we asked them to hand out informed consent forms to the parents of each child in their group. Parents of 40 children signed the consent form, however, 8 children were excluded because they had previous knowledge about the presented stories. All the participants were typically developing children, and no neurological or other disorders were reported by their parents; 84% of the children use smartphones or tablets at least weekly, and the rest of them had no earlier experiences with touchscreen devices. All children involved in our study were prereaders. The study was approved by the local ethics committee (2020-108) and was carried out under the Declaration of Helsinki. All children have verbally agreed to participate.

3.2.2. Instruments

3.2.2.1. The storybooks. Since in Experiment 2 we used a within-subject design we needed stories that could be compared with each other therefore we selected the *Berry and Dolly: Four Seasons Book* by Erika Bartos. The selected book contains four stories with similar styles featuring Berry, the snail, and Dolly, the ladybug. Each story is related to a particular season (Winter Tale, Spring Tale, Summer Tale, and Autumn Tale) and presents a simple story about it (e.g., building snowmen, planting flowers, making pancakes, or visiting a

Table 2
Descriptive data of the stories in Berry and Dolly: Four Seasons Book by Erika Bartos.

Tale	Pages	Words	Words/pages	Interactions
Winter Tale: The Snow Owl	13	411	31.6	3.2
Spring Tale: Dolly's flower	12	408	34	3.8
Summer Tale: Pancake Party	13	423	32.54	3.4
Autumn Tale: Harvest	13	417	32.1	2.8

grape harvest). The stories are age-appropriate and commercially available both in print book format and as an interactive storybook. The print book was published by Pozsonyi Pagony publishing house in Hungary. The *interactive storybook* versions were developed by the ONCE Digital Arts Ltd. and they are available through Google Play and AppStore in Hungarian and English (e.g., https://apps.apple.com/us/app/winter-tale-berry-and-dolly/id1208958373). Each story has 13 pages, one page contains 32 words and 3.3 interactions on average. Multimedia elements like animations, sound effects, and narration were available as well. The stories were equal in the terms of complexity, vocabulary, and the number of interactive features and multimedia elements. Further information about the stories is presented in Table 2. For the *multimedia-only condition*, we made screen videos of each interactive storybook to exclude the interactive features and keep the multimedia elements including the narration. We presented these screen videos to the children. Audio recordings of the interactive storybook applications were also made for the *audio condition*. Audio recordings were used to ensure the same auditory input for each child. The stories were presented using a Meizu M6 Note 5.5" touchscreen device. For the exposure three story were selected randomly from the available four.

3.2.2.2. Recall performance. We asked children to answer ten questions (henceforth named *short Q&A*) related to the plot of the story (e.g., "What did Berry make?" and "What ingredients were used for the pancake?" etc.). Answers were rated on three-point scales between 0 and 2 points by the experimenter and two additional independent scorers. The same rating system was used as in Experiment 1. The agreements between the scorers were tested using Kendall's coefficient of concordance. Inter-rater reliability was 0.923 ($p < .001$), indicating high correspondence between the scorers.

3.2.2.3. ADHD Rating Scale-IV preschool version. One caregiver of each child was asked to complete the Hungarian version of the ADHD Rating Scale-IV [56] about the children. The 18-item questionnaire measures inattention, hyperactivity, and impulsivity between the age of 5–18 years [57] on two subscales: inattention and hyperactivity/impulsivity. Each item is rated on a 4-point Likert-type scale ranging from 0 (never or rarely) to 3 (very often) according to which number best describes the behavior of the child over the past six months. The questionnaire has excellent psychometric properties, in this study the McDonald's ω was 0.949 for the inattention and 0.926 for the hyperactivity/impulsivity subscale.

3.2.2.4. Attentional performance. We used the Chair-lamp Task [58] to measure the attentional performance of the children. This is a timed paper-and-pencil test to assess sustained and selective attention in children from the age of 5. The task requires resistance to fatigue and high concentration. It consists of a test sheet that portrays 399 black-and-white simple figures (e.g., lamps, chairs, flowers, fruits, etc.) on both sides of the paper. Children are asked to mark as many chairs and lamps as they can find with a single line and ignore the other figures. They have 5 min to work on the task. To evaluate their performance the total number of attended figures (N), the total number of errors (E), and the total number of omissions (O) were registered. We used these measures to calculate the attention quality index (AQI) using the following equation: $((E + O)/N)100$. Note, that higher scores indicate *worse* performance. Achieved scores in this study ranged from 0.2 to 11.42 points.

3.2.2.5. Working memory (WM) capacity. The Digit Span Task [59] was used to measure the WM capacity of our participants. Children were asked to listen carefully to a sequence of digits and then repeat them in the same order. The number of digits increases by one after every two sequences. The task ended if the child made errors in two consecutive same-length sequences. The total number of correctly recalled sequences was used as an indicator of WM capacity. Higher scores indicate greater WM capacity. According to Wechsler's rating system children could achieve 16 points on both versions. Achieved scores ranged between 4 and 11 points.

3.2.3. Procedure

Children were introduced to three different stories from the book in three different formats in separate sessions. The interactive and multimedia stories were presented using a Meizu M6 Note touchscreen device (with a 5.5-inch screen). The interactive storybook condition was identical to Experiment 1, and in the audio condition (which served as the control condition) children listened to an audio recording of the story. In the multimedia-only storybook condition children held the mobile device and watched the storybook without interactions. Data were acquired in three separate sessions. In each session, children were exposed to one story, directly followed by a short Q&A; then in the first session, we assessed their WM capacity, and in the second session their attentional performance. All the children participated in each session. The order of the stories was counterbalanced across children and conditions. Each session lasted about 30 min. Similarly, to Experiment 1 the study was conducted in a spare, quiet room at the preschool. The children participated individually, only the experimenter was present. All children received a small reward for their participation.

Table 3
Pearson follow-up correlational coefficients and *p* values between recall performances (total, and separately for the three book formats) and the four covariate variables used in the GLMs. Significant main effects and interactions regarding the GLMs are labeled in italics.

	Book Format							
	Total		Audio		Interactive		Multimedia only	
	r	p	r	p	r	p	r	p
Hyperactivity/Impulsivity	−.303	.092	−.038	.838	−.333	.062	−.332	.064
Inattention	*−.434*	*.013*	−.185	.309	−.509	.003	−.278	.125
AQI	*−.398*	*.026*	*−.045*	*.810*	*−.456*	*.010*	*−.430*	*.016*
Working memory	.332	.064	.164	.369	.456	.009	.095	.606

3.2.4. Statistical analysis

Statistical analyses were performed using the JAMOVI Statistics Programme (Version 1.2.27.0 for Windows). Outliers (number of recalled words more than 2 SD from the mean) were excluded, approximately 1% of all the collected data.

First, to test the effect of the book format on recall performance we used a GLM analysis, where the within-subject factor was the medium of the book (audio, multimedia only, interactive). Follow-up pairwise comparisons were adjusted for multiple comparisons using Tukey's procedure. Afterward, we performed four separate GLMs to test if individual differences in WM capacity, attentional performance, and hyperactivity/impulsivity influenced recall performance. Digit Span Task scores, AQI scores, and the sum totals of the Inattention and Hyperactivity/Impulsivity subscales of the ADHD Rating Scale-IV were entered as covariates, in separate analyses. We used Pearson correlations to follow up on the significant covariation effects.

3.3. Results

As expected, we found a significant main effect of book format (F (2,62) = 9.57; $p < .001$; $\eta p^2 = 0.236$). Tukey corrected pairwise comparisons revealed that children's recall performance was better both in the multimedia only (t (31) = −3.98; $p < .001$) and in the interactive storybook conditions (t (31) = −2.92; $p = .017$) compared to the audio condition. The multimedia-only storybook condition and the interactive storybook condition did not differ (t (31) = −1.76; $p = .200$).

The Inattention subscale of ADHD Rating Scale-IV (F (1,30) = 6.97; p = .013; $\eta p^2 = 0.189$) had a significant effect on recall performance. Since we did not find an interaction between inattention and recall performance (F (2,60) = 2.38; $p = .101$) we used the mean performance values for the follow-up Pearson correlation. The correlation revealed a moderate negative relationship between inattention and the mean values of recall performance. For the exact statistical values see Table 3.

AQI scores (F (1,29) = 5.47; $p = .026$; $\eta p^2 = 0.159$) had a significant effect on the recall performance and the interaction between recall performance and the covariate variables occurred for the AQI scores was also significant (F (2,58) = 3.23; $p = .047$; $\eta p^2 = 0.100$). AQI showed a moderate negative correlation with the recall performance in the interactive and the multimedia only conditions, but not in the audio conditions. For the exact statistical values see Table 3, results are reported visually in Fig. 3.

The Hyperactivity/Impulsivity subscale of ADHD Rating Scale-IV (F (1,30) = 3.03; $p = .092$) and WM capacity (F (1,30) = 3.71; $p = .064$) had no significant effect on the recall performance of the children. Interactions were nonsignificant regarding Hyperactivity/Impulsivity (F (2,60) = 1.56; $p = .219$) or WM capacity (F (2,60) = 2.84; $p = .066$). Means and standard deviations are reported in Table 4. The Benjamini–Hochberg false discovery rate procedure was used to correct for multiple comparisons [37–39].

3.4. Discussion

In Experiment 2 we aimed to test whether individual differences in the maturation of executive functions affect the efficiency of encoding new information when using electronic storybooks. In line with the result of Experiment 1, and the framework of the cognitive theory of multimedia learning [23], multimedia elements and interactive features significantly improved recall performance compared to the audio condition, underscoring their importance in knowledge acquisition. Furthermore, in line with earlier studies (see Refs. [46,60]), we found that children with less efficient selective and sustained attention skills performed worse on the short Q&As in comparison to those without attentional difficulties. However, results on the ADHD Rating Scale-IV showed no relationship between inattention and recall performance across conditions. The ADHD Rating Scale-IV measures inattention as a broad phenomenon. Besides children's behavior is rated by the caregiver which might bias our results. In contrast, the chair lamp task provides a more accurate view of the attentional abilities of the children as it is based on their actual performance rather than the caregivers' perception and it focuses solely on sustained and selective attention rather than a broad range of inattention symptoms. According to our results, it seems that recall performance is influenced equally by inattention in all three conditions, however, recall performance in multimedia and interactive conditions depends more on that how well children can sustain their attention and select relevant stimuli between distractors. This supports our hypothesis that focusing on relevant information in the presence of multiple multimedia elements and interactive features can be demanding for children with attentional problems. The loss of performance may occur from the potential temporal discrepancy between narration and interactive features [29,53]. Unlike multimedia elements, interactive features are controlled by the user [4] and thus, the narration and interactive features may dissociate in time. That is, there is a time lag between interactive features and upcoming information. The dissociation may result in a higher cognitive load and might also be a source of distraction. Based on the *cognitive load theory* [28], the simultaneity of elements of different modalities in the terms of content

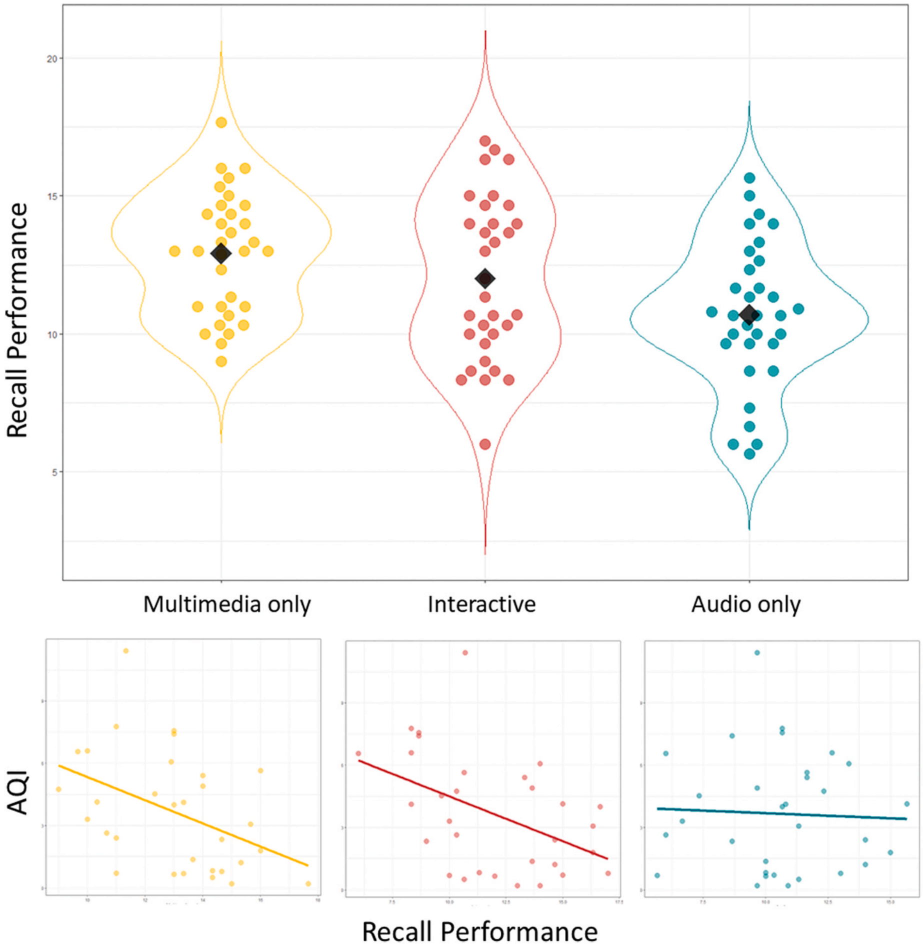

Fig. 3. Top panel: The distributions of recall performance on the Short Q&A (number of correct answers) in the three conditions (multimedia only, interactive and audio). Bottom panel: The correlations between attention quality index (AQI) and recall performance by the same three conditions. Higher values are corresponding to worse performance on the AQI. The same colors indicate the same conditions. Black diamonds show the mean scores, dots represent the actual score of participants. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Means and standard deviations of the recall performance for the Audio, Interactive, and Multimedia only conditions. Means and standard deviations regarding the two subscales of the ADHD Rating Scale IV, attention quality index (AQI) of the Chair-lamp Task, and scores on the Digit Span Task are also reported.

Task		Mean	SD
Book Format	Audio	10.7	2.60
	Interactive app	12	2.95
	Multimedia only app	12.9	2.18
	Total	12	2.13
ADHD Rating Scale-IV.	Inattention	8.06	5.89
	Hyperactivity/Impulsivity	6.91	5.88
	Total	15	11
Chair-lamp Task	AQI	3.66	2.81
Digit Span Task	Forward	5.97	1.86

and time is a prerequisite for efficient multimedia learning and diminishes cognitive load. In the present study, the extraneous load might arise from the high number of simultaneously presented multimedia elements and from the interactive features that can be repeated indefinitely. Future studies should test these assumptions. In the audio condition, neither WM nor attentional mechanisms influenced recall performance. Hyperactivity and impulsivity had no effect in either condition. The influence of individual differences on information processing was already proven to be relevant regarding factors like the level of self-efficacy [61], however, our results gave further significance to the importance of examining individual differences in this area.

4. General discussion

Electronic storybooks have a growing popularity among parents and educators. These applications provide a great opportunity for playful learning (e.g. Refs. [18-20], but the benefits of the multimedia elements and interactive features used in these applications are not always evident, especially in the long term [24,25]. It is still not known whether the multimedia elements in a storybook facilitate the encoding of new information or mitigate forgetting it. A possible reason behind the mixed result is that the efficiency of information processing through electronic storybooks varies greatly as there are great individual differences in the maturity of executive functions (e.g., attentional control and WM capacity) in children. Hence, we designed two experiments to investigate how multimedia and interactive features in electronic storybooks improve recall performance in children, accounting for individual differences in attentional processing and WM capacity. In Experiment 1, we focused on the long-term effects of using an electronic storybook application to test whether multimedia elements and interactive features affect encoding or forgetting. We hypothesized that children using interactive electronic storybooks will recall more accurate information than children in the Print Book group and this improvement will persist over time. As we predicted the recall performance in the short Q&As of children in the interactive application group was significantly better compared to the Print Book group. In line with [62] this improvement persisted over time, i.e., the difference between the groups did not change three weeks later. Thus, the multimedia features facilitated encoding but did not mitigate forgetting. Besides being an important addition to the literature that lacks longitudinal data [24], this also suggests that electronic storybooks can be effectively used to *transfer* new knowledge and the acquired information is better retained in long-term memory.

In Experiment 2, we were interested in the cognitive factors accounting for efficient encoding. We hypothesized that using interactive features will be more demanding for those with less matured executive functions, while multimedia elements will improve recall performance regardless of individual differences in executive functioning. We replicated the results of Experiment 1, as interactive features, and multimedia elements improved recall performance in children between the age of 5 and 6 years. However, we also found that children with poorer sustained and selective attentional abilities performed worse in multimedia and interactive conditions. These results only partially support our hypothesis because, contrary to our assumption, the processing of multimedia elements is also affected by the maturity of executive functions. Our results are in line with the attention as a “gatekeeper” for WM theory [43,63]. Taken together we showed that although multimedia elements and interactive features can support encoding, individual factors – such as sustained and selective attention – also have an important role in the efficiency of encoding. This also broadens our understanding of precisely what executive functions are important to focus on for teachers if they use multimedia and interactive features in their classes. These results could also be used by developers of electronic storybook applications to build an environment that can be customized based on individual needs and differences.

Our second experiment supports that in electronic storybooks with embedded multimedia elements and interactive features, the ability to select relevant information and ignore the irrelevant ones may have particular importance. Information processing is most effective when children can orient their attention toward those stimuli presented on the screen that are relevant to the current activity. This highlighting is modulated by the efficiency of top-down control functions [64] which is determined by the maturation of the executive attention network [49]. It has been shown that information processing is more stimulus-driven in children with less matured executive attention network (and, hence, poorer cognitive control functions), therefore they are more easily distracted by salient stimuli on the screen compared to those with stronger cognitive control functions [50,65]. In the case of electronic storybooks, if a child attends to a piece of irrelevant information and only switches their attention toward the relevant stimulus later in time, there will be a mismatch between the narration and the embedded multimedia element. This mismatch may interrupt the integration of information coming through different modalities, which increases the cognitive load and decrease the quality of encoding – reflected in recall performance [28,30,44,63].

Although touchscreen devices easily capture and sustain the attention of the user [34], how visual attention is oriented within the screen is the concern here. Our results also point to the limitations of applying multimedia learning. Although multimedia learning is effective only under specific conditions, such as the congruency between narration and multimedia elements [23,28], our results suggest that individual differences in attentional control processes may modulate its effectiveness. This also underscores that the individual needs of children should be taken into account when choosing the right applications for (multimedia) learning. This is an important practical addition that parents and educators need to keep in mind, and developers need to address.

Although our findings are novel, we should acknowledge certain limitations in the current investigation, and encourage conceptual replication of our work using other techniques. Our first limitation is that, although we sought to get a complex view of participating children's cognitive abilities, we had to consider the limited attentional span and working capacity of preschool-aged children. To avoid mixed results due to fatigue, we limited the number of measurements involved in our study to an attentional and a WM test. In future measurements of verbal abilities and attentional networks, e.g., the child version of the Attention Network Test [66], might be included. The latter would be helpful to draw more accurate conclusions about the relationship between various attentional mechanisms and the processing of interactive features and multimedia elements. To better understand the underlying mechanisms of multimedia learning measurements of cognitive load should also be involved in the future [67]. The second limitation is the laboratory setting which lessens the generalizability of our results. We sought to control as many variables as possible, and thus, the experiments took place in a laboratory setting, i.e., during the data collection only the child and the experimenter were present in a spare, quiet room. To increase the extent of generalizability of our results, and to gain more validity, future experiments need to explore the effectiveness of electronic storybooks in a more common environment, like at home or in a classroom. Finally, we assumed that processing multimedia elements and interactive features consume more attentional resources, but we have limited information about the underlying mechanisms. The third limitation is that we could not monitor eye movements and count the number of interactions used during the presentation of a storybook. These variables would prove to be useful to gain a deeper understanding of how individual differences affect information processing when using multimedia elements and interactive features. Finally, we only measured recall performance after three weeks which limits the generalizability of our results of how electronic storybooks help the acquisition and retrieval of new knowledge from long-term memory. Future studies should measure performance after several months or a year to get more pronounced results in this field.

Despite these limitations, we have demonstrated that electronic storybooks have the potential to support knowledge acquisition in preschoolers by providing a playful learning environment with embedded interactions and various multimedia elements. This has also been shown to be persistent over time, providing further confirmation of the effectiveness of using electronic storybooks in learning. Since the results of Experiment 1 and Experiment 2 are highly similar even though they included two different samples and were collected with different methods, we think this also adds to the robustness and replicability of our results. The results of Experiment 2 also highlight that, children with poorer sustained and selective attention process information less efficiently through multimedia elements and interactive features than their peers. This may explain why the advantages of electronic storybooks are not observable in some cases and also draw attention to the importance of taking individual differences into account in this field of study.

These findings not only emphasize the importance of individual needs regarding digital educational environments but may also guide parents and educators on how to use them, and developers on how to develop them. Children can benefit from using electronic storybooks; however, the amount of improvement depends on the maturation of attentional processes. To reduce cognitive overload, developers should focus on temporal contiguity (see Refs. [29,30]) and lessen the number of potential distractors. Features supporting the orientation of attention toward relevant the relevant part of the screen should be implemented. Future studies should identify the traits that support focusing on relevant information and understanding the story. While interactive storybooks likely cannot replace the benefits of having a real-life mentor, the immediate feedback and the multisensory stimulation provided by these storybooks can still be useful. Future studies need to focus on understanding the exact mechanism of these features in learning and how this technology could be best utilized.

Author contribution statement

Cintia Bali: Conceived and designed the experiments; Performed the experiments, Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data, Wrote the paper.

Timea Matuz-Budai; Nikolett Arato; Labadi Beatrix: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Andras N. Zsido: Conceived and designed the experiments; Performed the experiments; analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data, Wrote the paper.

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Data availability statement

Data associated with this study has been deposited at https://osf.io/p8vz2/?view_only=fce4c8bfbe3b4d54b12038307fef21aa.

Declaration of interest's statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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