Individual Differences in Word Learning from Print and Digital Shared Book Reading

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Abstract

Shared book reading is an important context for children's vocabulary development. Yet, the process by which word learning is influenced by the characteristics of both the learning material and the learner remains poorly understood – particularly in relation to contemporary digital literacy practice. We examined the effects of book format (print vs. digital) and individual differences in prior vocabulary knowledge and executive functions on children's word learning. English-speaking caregivers and their 4- to 5-year-olds took part in this study (N = 99; child's M_{age} = 57.5 months; 57.6 % girls). In a cross-sectional, within-subjects design, dyads read one of two custom storybooks in print, and the other in digital format, with order of book and format presentation counterbalanced across participants. Word learning was assessed with tests of production, definition, and comprehension. There was no evidence of a main effect of book format across word learning measures, however, several child characteristics influenced word learning. Prior vocabulary knowledge predicted performance on all word learning measures, boys were more accurate than girls in tests of definition and comprehension, and executive functions significantly predicted performance in the definition test. In addition, there was a significant cross-over interaction between book format and executive functions for the comprehension test scores. In the digital book condition only, higher comprehension test scores were obtained by children who scored more highly on the measures of executive functions. Overall, these findings underscore the importance of considering individual differences and multiple outcomes when studying learning from different media.

Keywords: word learning, shared book reading, digital media, vocabulary, executive functions, individual differences

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Vocabulary in early childhood is strongly predictive of later reading comprehension, academic achievement, employment, and well-being (Law et al., 2009). Shared book reading is a critical context for early word learning, because the language of storybooks is lexically richer than child-directed speech (Montag et al., 2015). The nature of the shared book interaction makes a difference: Children learn more words when caregivers scaffold word-learning opportunities (Flack et al., 2018). Reading digital books with young children is becoming increasingly common (Kucirkova, 2019), opening up opportunities and challenges for young learners. While the comparison of word learning across print and digital media has received substantial research attention, findings are mixed, and only a few studies to date have directly contrasted print and digital shared book reading to isolate the effect of book format in naturalistic settings (Savva et al., 2022). Furthermore, the role of children's inter-individual differences is likely important but under investigated in the contexts of print and digital shared book reading. In this novel study, we examine the impact of book format and individual differences in vocabulary knowledge and executive functions on children's word learning during print and digital shared book reading with a caregiver.

Shared book reading explains unique variance in 4- to 5-year-olds' vocabulary skills (Mol & Bus, 2011), and shared book reading interventions have positive effects on children's vocabulary development (Dowdall et al., 2020). Given the critical role of shared book reading in children's vocabulary development, it is crucial to understand how the characteristics of the learning materials and those of the learners influence word learning. In the contemporary digital ecology, where digital books are increasingly common, an important difference in learning materials concerns the medium of presentation, or book format (Kucirkova, 2019). As stated above, research on the effect of book format on word learning provides a mixed and inconclusive set of findings (Furenes et al., 2021; Hare et al., 2024; Savva et al., 2022), of

which we offer a critical review in the next section. Notably, the mechanisms underlying differences in learning between formats are not fully understood. We argue that this is due to two main methodological and conceptual limitations: first, research designs that do not allow researchers to disentangle the effect of book format from that of embedded features; and second, analytic strategies that neglect learner characteristics and do not examine possible interaction effects.

It is important to examine interaction effects between the characteristics of the learner and learning material because both general developmental frameworks and media-specific models point in this direction. Specifically, the dynamic system framework (Thelen & Smith, 1994) underscores the importance of examining the dynamic interplay between children's inter-individual differences and the characteristics of the external environment, including the learning material. Similarly, and more locally, media-specific models such as the capacity model (Fisch, 2000) and the differential susceptibility to media effects model (Valkenburg & Peter, 2013) propose that media effects are conditional on the characteristics of the learner. In particular, the capacity model highlights characteristics of the learner, including prior knowledge and working memory, as well as those of educational material, as important predictors of learning, and notes that they may interact with each other.

In the following sections, we review the literature on the effects of book format and child characteristics on word learning from shared book reading. We then outline the research questions and hypotheses tested in the current study.

Effects of Book Format on Word Learning

Print and digital books differ in important ways. Print books typically serve the function of reading. For young children, they remain the preferred format for shared reading (Eutsler & Trotter, 2020). In contrast, digital books are accessed through handheld devices such as iPads and tablets, that can be operated in different ways and for purposes other than

reading, such as streaming, playing, etc. In light of these experience-related differences, digital books, even in the absence of additional features, may bring specific challenges. A study of shared book reading between caregivers and their 4.5-year-olds found that adults talk more about the format and the environment in the digital format than the print format, but they provide more content-related evaluative comments in the print format than the digital format (Krcmar & Cingel, 2014). Similarly, a study analysing shared reading interactions between a mother and her 5-year-old child, found that the dyad engaged in more behaviour-related talk with the digital than the print format, and that the frequency of non-immediate talk was lower in the digital than print format (Ozturk & Hill, 2020). Taken together, these findings from naturalistic studies suggest that the digital format might be less effective in supporting word learning than print, because it is more prone to distraction and encourages less language boosting behaviour.

A wealth of prior research has investigated the effect of book format on word learning from shared reading, but recent meta-analytic syntheses highlight a mixed and inconclusive set of findings (Furenes et al., 2021; Savva et al., 2022). Furenes et al. (2021) found that the digital format had a significant and positive effect on word learning for children aged between 1 and 8 years. However, when the authors imputed studies with small sample sizes due to asymmetry around the point estimate, the effect size reduced and was no longer significantly different from zero. As a result, Furenes et al. (2021) concluded that the positive effect initially found for digital books might not be robust in every context. Savva et al. (2022) reported an overall moderate positive effect of e-books on word learning in children aged between 3 and 8 years. Yet it should be noted that this meta-analysis included e-books with different multimedia and interactive features and compared those e-books with either print books (presented with or without adult support), or “static” e-books with audio narration.

To disentangle the effect of book format, adult mediation, and digital features, Savva et al. (2022) conducted separate meta-analyses on subsets of studies. When static e-books without multimedia and interactive features were compared to print books, and thus the book presentation format was isolated, only five studies provided eligible data. In this subset of studies, which included "basic" e-books, there was a small, negative but non-significant effect of the digital format on word learning. When considering receptive and expressive word learning measures separately, different patterns of results emerged. A small negative non-significant effect of digital format on a receptive vocabulary measure was found when aggregating the five eligible studies. Only two studies provided eligible data for analysing the effect of book format on expressive vocabulary. In this smaller subset, a positive effect of "basic" e-books on expressive vocabulary was found. Taken together, these findings do not provide robust or conclusive evidence about the effect of book format on word learning; few studies have attempted to isolate the effect of book format while controlling for child characteristics, and different patterns of results are apparent for receptive and expressive vocabulary measures.

Effects of Child Characteristics on Word Learning

Child characteristics play an important role in word learning. Specifically, vocabulary knowledge predicts young children's word learning from print storybooks (Sénéchal et al., 1995). Visual attention during the task has been linked to word learning from print and digital shared book reading (O'Toole & Kannass, 2018), and working memory, inhibitory control, and executive functions each predict young children's word learning in experimental tasks (Gathercole et al., 1997, 1999; Kapa & Erikson, 2020). While there has been less work exploring their role in word learning from shared reading (for an exception, see Hadley et al., 2021), a consideration of these varied skills is critical to understanding the source of any differences between book presentation formats. We acknowledge that age and gender might

also play a role in word learning from shared book reading; for example, older preschoolers show a word learning advantage (e.g., Reich et al., 2019). Girls appear to learn fewer words than boys when reading informational books (Bergman Deitcher et al., 2019), but other studies show a word learning advantage for girls compared to boys (Reich et al., 2019). Although these variables are not the main focus of the current study, we control for both gender and age in our analyses to provide unbiased estimates of the effects under investigation.

The empirical evidence on possible interactions between book format and child characteristics to date is scant. In children aged 10 to 13 years, reading comprehension is lower when reading independently on screen relative to print, but this *screen inferiority effect* is observed only in children with lower reading skills (Salmerón et al., 2021). In the context of shared reading, a meta-analysis including studies of preschool and elementary school children has shown that the multimedia features of digital books are more effective for children with, or at risk for, low literacy skills (Takacs et al., 2015). Furthermore, contingent digital enhancements benefit story comprehension of pre-school children, particularly those with less developed attention regulation (Eng et al., 2019). This empirical evidence underscores the need to explore possible interaction effects between book format and child characteristics in young children. This is further motivated by the capacity model (Fisch, 2000), which highlights the critical role of children's prior knowledge and working memory capacity in predicting comprehension and learning from digital media. For these reasons, we consider the role of prior vocabulary knowledge and broader executive functions in word learning from print and digital shared reading.

The Present Study

The present study was designed to address critical gaps in our knowledge about the effects of book format and learner characteristics on young children's word learning during

naturalistic shared book reading. We used a within-subjects paradigm to isolate the effect of book format on word learning, and we assessed vocabulary knowledge and executive functions to examine the influence of individual differences in these skills. We carefully controlled what caregivers and children read and the format in which they read, but not *how* they read. This was done to achieve a trade-off between ecological validity and experimental control, thereby increasing the likelihood that our findings will generalise to real-life situations. We addressed the following research questions:

1. Does book format (print vs. digital) influence young children's world learning during naturalistic shared reading while controlling for individual differences in vocabulary knowledge and executive functions?
2. Does book format interact with vocabulary knowledge and executive functions to influence word learning during naturalistic shared reading?

If the book format affects the word learning process during naturalistic shared reading, we should observe a significant and meaningful effect of book format on word learning, after controlling for individual differences in vocabulary knowledge and executive functions, which are established important determinates of word learning (Hadley et al., 2021; Kapa & Erikson, 2020; Sénéchal et al., 1995). Observation studies of shared reading interactions suggest that the digital format is associated with more distractions and fewer language boosting behaviours from caregivers (e.g., Krcmar & Cingel, 2014). Meta-analytic synthesis of word learning outcomes, albeit from a small set of studies isolating the effect of the medium, indicates that the digital format has a small negative but non-significant effect on receptive measures, and a significant positive effect on expressive measures (Savva et al., 2022). Due to these contradictory findings, we did not make directional predictions about the effect of book format on word learning from naturalistic shared reading.

If individual differences in vocabulary knowledge and executive functions play a distinct role in word learning from different media as theory might suggest (Fisch, 2000; Thelen & Smith, 1994; Valkenburg & Peter, 2013), we should observe a significant interaction between these child characteristics and book format. Research with older children focusing on reading comprehension outcomes from independent reading, suggests that the digital format has a negative impact on performance only in children with lower literacy skills (Salmerón et al., 2021). If these findings extend to younger children and word learning measures, the digital format should be detrimental for children with lower skills.

Methods

Participants

Ninety-nine British English-speaking caregiver-child dyads took part in this within-subjects study. The sample size was decided a priori, informed by previous high-powered studies (Reich et al., 2019). The use of a within-subjects design further increased the power to detect statistically significant and meaningful effects. Children were typically developing, as reported by their caregivers, and aged between 48 to 71 months (M_{age} = 57.5; SD = 7.15; 57.6 % girls). Participating caregivers were predominantly highly educated individuals, with 75% achieving an undergraduate degree or higher. Caregivers were aged 29 to 47 years (M_{age} = 37.76; SD = 3.93; 83 self-reported as females; 6 as men; 10 did not state). Nine additional participants were tested but excluded due to missing data on key variables, following the protocol outlined in our pre-registration. Concerning children's experience with shared book reading, 86% of caregivers reported daily print-based shared reading, while only 1% reported daily digital-based shared reading (see Table S1). Further sociodemographic characteristics of the sample are reported in Table S1 in the Supplementary Materials.

Participants were recruited via the university database, social media advertisements, and flyers distributed in public book libraries in a middle-sized town in the North West of

England. This was complemented by a snowball strategy, where participating caregivers were asked to share the study flyer with their own social networks. Written informed consent was obtained from caregivers prior to data collection. Children received a book, and caregivers received a travel reimbursement for their participation. This research received ethical approval from the Faculty of Science and Technology, Lancaster University (reference number: FST-2022-0791-RECR-3). The shared book reading sessions were video recorded. Video recordings were securely stored, with exclusive access to the members of the research team. Observation of videos took place in dedicated coding rooms on campus. Caregivers were provided detailed information about data protection and had the opportunity to ask questions before signing written informed consent to participate in this study.

Measures

Vocabulary Knowledge

Children completed a standardised vocabulary assessment: the Word Classes subtest of the Clinical Evaluation of Language Fundamentals – Preschool-2 UK (CELF-P2; Wiig et al., 2004). Children are shown three to four pictures (e.g., apple, shoe, bread), while the experimenter names each picture aloud. They are instructed to identify the two words that go together best (e.g., apple and bread) and explain how they go together (e.g., both are food). They get 1 point for each correct response, summed to provide a receptive, expressive, and total vocabulary score. This assessment was selected to go beyond single word comprehension and capture the depth of vocabulary knowledge. Both internal consistency (.78 - .95) and test-retest reliability (r = .78 -.90) reported in the test manual are adequate (for a comparison of psychometric properties with other standardised language assessments see also Denman et al., 2017).

Knowledge of Target Words

Caregivers completed a vocabulary checklist designed after The MacArthur Communicative Development Inventories (Fenson, 2002) as a proxy for their child's knowledge of target words (see Shi et al., 2022 for a similar approach). For each target word, caregivers stated whether their child understood (receptive knowledge) and also understood and said (receptive and expressive knowledge) the target word or not. One point was assigned if receptive or receptive and expressive knowledge were marked as present by caregivers; otherwise, 0 was assigned.

Executive functions

Children completed the visual attention subtests of the Developmental Neuropsychological Assessments (NEPSY; Korkman et al., 1998). These subtests are designed to assess the speed and accuracy with which a child can focus selectively on and maintain attention to visual targets (e.g., animals, faces). Children are asked to mark with a crayon, as quickly and as accurately as possible, visual targets across two arrays containing both targets and distractors. An accuracy score is calculated by subtracting the number of non-target marked (commission errors) from the target marked correctly. The total score is determined using the accuracy score in conjunction with the time taken to complete the task (speed). Different materials are used for different age groups, with difficulty increasing with age. For this reason, scaled (not raw) scores are reported and used in the analyses. The reliability reported in the test manual is adequate, as indicated by the split-half reliability for the attention domain (range .70 - .82) (see also Ahmad & Warriner, 2001).

Two researcher-developed measures of verbal working memory were administered, based on the format of the measures used by Gathercole et al. (1997). In the forward digit span task, children are asked to repeat unique strings of numbers exactly in the same order as they heard them, starting from one digit. There are three trials at each level of difficulty, and testing ceases when the child gets two out of three trials wrong. In the backwards digit span,

children are instructed to repeat unique strings of numbers backwards. The same stopping rule is applied. There are two practice trials to model behaviour before the test trials. Children get 1 point for correctly repeated trials. The digit span has been used successfully in prior research with 4- to 5-year-olds and presents appropriate test-retest reliability (r = .77) (Gathercole et al., 1997).

Caregivers completed the Behaviour Rating Inventory of Executive functions, Preschool Version (BRIEF-P; Gioia et al., 2003), which provides a measure of executive functions (inhibition, working memory, shifting, planning/organizing, and emotional control), in ecologically valid settings. Partial agreement between the BRIEF-P subscales and laboratory-based tasks has been observed, thereby highlighting the complementary nature of these measures (Nin et al., 2022). Internal consistency of the BRIEF-P ranges from good to excellent: Alpha coefficients in the normative sample for the BRIEF-P parent and teacher reports are high (range = .80–.97) (Goldstein & Naglieri, 2014).

Storybook materials

Custom storybooks were developed using Canva Pro to ensure that the storyline would be unfamiliar to all participants and that all target words would be of comparable salience in the storyline. Our plots featured a canonical Western structure of exposition, conflict, and resolution. A similar structure has been successfully used in previous studies with 3.5 to 4.5-year-olds (e.g., Piazza et al., 2021). We controlled the size of the book across formats (single page size: 126 x 113 mm; open book / iPad screen size: 126 x 226 mm). The only difference was the medium of story presentation. Two storybooks with embedded low-frequency words were created in print and digital format so that each book served as the digital condition for half of the participating dyads, and the print condition for the other half. These are available on the Open Science Framework (OSF; https://osf.io/6uem9) under Creative Commons Attribution 4.0 International.

In experimental settings, word learning is often measured using pseudo-words paired with novel objects. This approach did not represent a viable option because, in our study, the caregivers read aloud the book to the children. Caregivers would struggle to read and explain pseudowords without significant prior training, limiting the ecological validity of our task. Therefore, to measure word learning, we identified real words that were unlikely to be known by children in our age range. Selection involved a range of criteria: their frequency in the SUBLEX corpus of children's tv programs (van Heuven et al., 2014); their age of acquisition (Kuperman et al., 2012); and examination of the high-difficulty items in standardised vocabulary assessments, such as the British Picture Vocabulary Scale (BPVS; Dunn & Dunn, 2009) (see Lenhart et al., 2020 for a similar approach). The following animal names: *myna, okapi, sloth,* and tools*: clamp, valve, and chisel* were selected. We also included one word in each category more likely to be known by children (e.g., *toucan, screw*) to support motivation and engagement with the storyline.

We embedded four target words in each story. Each word was repeated three times in the text and illustrated twice, over two successive pages. Previous studies using the same learning schedule (i.e., 1 story repetition, with target words repeated 3 times within the story) have found evidence of word learning (e.g., Piazza et al., 2021). On its second mention, each target word was accompanied by an adjective describing its visible property. This was to promote the encoding of semantic features and reflect the rich semantic context in which words typically appear in storybooks. Psycholinguistic properties of target words and accompanying adjectives are reported in Table 1.

Table 1

Frequency and Age of Acquisition of Target Words and Accompanying Adjectives

	Story A			Story B	
	Frequency	AoA		Frequency	AoA
Target words					
okapi	2.23	11.22	clamp	2.71	10.89
sloth	3.38	8.37	valve	3.31	10.78
myna	2.23	9.5	chisel	2.93	10.53
toucan	3.71	8.69	screw	3.82	6.65
Adjectives					
striped	3.08	4.65	wooden	4.34	5.89
furry	4.62	5.72	shiny	4.32	5.05
dark	5.28	3.74	sharp	4.82	6.11
colourful	4.82	4.89	pointy	4.63	7.39

Note. Frequency of SUBLEX. Values lower than 3.5 are considered infrequent in the corpus. AoA = Age of Acquisition.

The selection of target words was further validated via a checklist designed after The MacArthur Communicative Development Inventories (CDI; Fenson et al., 1993). Before the shared reading activities, caregivers completed the vocabulary checklist as a proxy for their child's receptive and expressive knowledge of each target word (see Shi et al., 2022, for a similar approach). Our models predicting word learning controlled for knowledge of target words reported by caregivers.

Word Learning Assessments

Phonological and semantics aspects of word learning were assessed after the shared reading episodes. A five-minute delay was introduced to assess retention (in line with Hartley et al., 2020). Children completed a *production* test in which they were asked to name pictures of target words (Blewitt et al., 2009). Pictures were shown either on screen or on paper of identical size (126 x 226 mm), congruent with the book format (print or digital) in which the words were introduced during the shared reading. For each picture, the researcher asked,

"Tell me what this is called". The pictures were selected from the software Canva Pro. Similar to Blewitt et al., (2009), the images presented at test were depicting different exemplars of the target objects than those presented in the book. This was because we were not interested in the superficial mappings between specific images and phonological forms, but rather in word learning and generalisation to other category exemplars. Familiar words (dog, cat; pencil, spoon) were interspersed among the targets to maximise the opportunity for children to experience success during testing. Each correct response for a target word was assigned 1 point.

Children also completed a *definition* test, in which they were asked to describe what they knew about a word, without any picture present. We adopted the child-friendly procedure used in previous research (Blewitt et al., 2009). Children were introduced to a stuffed animal named ''Toby" and told that ''Toby does not know very many words.". For each target word, children were asked ''Can you tell Toby what a [target] is?". After their initial responses, follow-up prompts were given such as ''What else can you tell Toby about a [target]?" and continued until children could add no more information. Children were familiarised with the task via practice trials with familiar words (e.g., dog, cat, spoon, pencil). For each word, children received 1 point for each unit of relevant information provided (e.g., object function, physical properties). Inter-rater reliability was computed via an intra-class correlation (ICC) analysis with absolute agreement (ICC = .95) (representing excellent agreement, Cicchetti, 1994).

Finally, children completed a *comprehension* test, in which they were asked to identify referents of the target words in a multiple-choice task (see Blewitt et al., 2009 and O'Toole & Kannass, 2018 for a similar approach). Children were asked to ''Find the [target, e.g., okapi]" on a page of four pictures. Each page depicted the target item (e.g., okapi) and three distractors: an item from the same superordinate category as the target (e.g., zebra), an item

from the story (e.g., myna), and an item from the same superordinate category as another story word (e.g., parrot). Pictures of target words were selected from Canva Pro and were different from those presented in the story. There were practice trials using familiar non-target words (e.g., dog, cat, spoon, pencil). For each target item, children received 1 point for a correct response. Chance level in this task was 25%.

Procedure and Design

Dyads were invited to the University Infant and Child Study Centre. The study took place in an observation room that enabled non-intrusive audio and video recording of caregiver-child shared reading interactions. After greeting the participating dyad and establishing a rapport, the experimenter administered the first subtest of the visual attention assessment (NEPSY; Korkman et al., 1998) to the child, while the caregiver completed the vocabulary checklist of the target words. Dyads practiced turning the pages on the experimental iPad with a mock story. Subsequently, caregiver-child dyads were instructed to read the two books. Dyads received the following instructions: "*I would like you to read together as you would do at home. Please take your time, I will be back when you are finished*". The dyads sat on a sofa and were left alone in the observation room. The experimenter observed and video-recorded the shared reading interactions from the control room[1].

In a within-subjects design, each dyad read a book presented on paper and a different book presented on an iPad, with the order of both format and story presentation counterbalanced across participants. After the shared reading activity, the child was administered the second subtest of the visual attention assessment, the target vocabulary learning measures, and a picture sequence task, while caregivers completed the BRIEF-P

[1] In-depth analysis of caregivers' verbal and gestural scaffolding is discussed in a separate manuscript. Overall, caregivers provided significantly fewer verbal and gestural scaffolds with digital than with print books.

(Gioia et al., 2003). Children completed the standardised vocabulary assessment and the working memory assessments, either after a short break or within 12 days of the first visit, depending on child compliance and dyad availability.

Analytic Plan

Statistical Models

We fit separate Generalized Linear Mixed Models (GLMM; Baayen et al., 2008) for each word learning measure (i.e., production test, definition test, and comprehension test). We specified binomial error structure and logit link function for binary outcomes (i.e., production test, comprehension test), and Poisson family for count data (i.e., definition test). The full random effect structure supported by the data was included in the models (Matuschek et al., 2017). Convergence issues were addressed according to a stepwise procedure: first by increasing the number of iterations, then using different optimisers, and, as a last step, by simplifying the random effect structure.

Research Question 1. To investigate the effect of book format (print vs. digital) on word learning, we compared a model (M_1) including our test predictor (book format) with a model (M_0) lacking our test predictor but being otherwise identical. Both models controlled for vocabulary knowledge, knowledge of target words, executive functions, age, and gender[2], all entered as fixed effects, to estimate any unique effect of book format.

Research Question 2. To investigate the interaction of book format and child characteristics (individual differences in vocabulary knowledge and executive functions) on word learning, we compared a model (M_2) including the interaction terms of interests with a model (M_1) lacking these interaction terms but being otherwise identical. Both models controlled for age and gender and knowledge of target words, all specified as fixed effects.

[2] Here we use the term gender in line with the previous literature and to acknowledge the fact that language literacy development is embedded in a socio-cultural context. Strictly speaking however, we classed our child participants based on caregiver reported biological sex.

Transformations

Our independent variable was categorical with two levels: print and digital. It was dummy-coded with print as the reference category. Age in months was z-transformed to facilitate the interpretation of model coefficients and to ease model convergence. There were moderate to high correlations between our measures of executive functions (see Table S2, Supplementary Materials). We conducted a Principal Component Analysis (PCA) for dimension reduction, adopting the procedure detailed by James et al. (2021). Analyses were conducted in R with the package psych (Revelle, 2023). A single executive functions component emerged according to Wayne Velicer's Minimum Average Partial (MAP) criterion, and applying the scree test (Cattell, 1966). The proportion of variance explained by this component was 47%. As expected, loadings were positive for visual attention (.70), forward digit span (.74) and backward digit span (.80), and negative for global executive functions (-.46), which provides an index of dysfunction, with higher scores indicating poorer executive skills. Given the extraction of a single component for executive functions, a single score resulting from our four executive functions measures was used in subsequent analyses.

Inference Criteria

To evaluate the significance of the contribution of our predictors, whilst avoiding multiple testing (Forstmeier & Schielzeth, 2011), we compared our full models with null models lacking our test predictors but being otherwise identical using the likelihood ratio test. The significance of the beta coefficients was indicated by $p < .05$. Marginal effects were plotted to provide a straightforward visualization of predicted probabilities for the results of the more complex models (Lüdecke, 2018). Significant interaction terms accompanied by improvement in the model fit, as indicated by a significant likelihood ratio test, indicated the presence of conditional effects. Marginal R^2 is reported to illustrate the proportion of variance

explained by the fixed effects, while conditional R^2 is reported to illustrate the variance explained by both the fixed and random effects.

Implementation

The models were implemented in R version 4.1.3 (2022-03-10) with the function glmer of the R package lme4 (version 1.1- 33) (Bates et al., 2015). Predicted probabilities were computed using the function ggpredict of the R package ggeffects, version 1.3.2 (Lüdecke, 2018).

Transparency and Openness

Our research questions, hypotheses, design, sample size, and analytic plan were pre-registered prior to data collection on the Open Science Framework (OSF; https://doi.org/10.17605/OSF.IO/ANCSX). Any deviation from the pre-registration is noted below. Fully anonymised data and analysis scripts are available on the project's OSF repository.

Results

Preliminary Analyses

Reading time across conditions was comparable, suggesting a similar level of engagement across conditions. On average, the print condition lasted 4 minutes and 33 seconds, and the digital reading condition lasted 4 minutes and 34 seconds. The means and standard deviations of our word learning measures grouped by condition (book format) computed at the single-item level are reported in Table 2. On average, children correctly labelled 25% of the items in the production test; produced .86 units of meaningful information per item in the definition test; and correctly identified 72% of the items in the comprehension test (chance level of 25%). The means, standard deviations, and correlations between child measures of vocabulary knowledge, executive functions, and each of the experimental word learning measures, collapsed over book format, are reported in Table 3.

There were small to medium associations between all measures. The means and standard deviations of word learning measures grouped by gender are reported in Table S3, in Supplementary Materials.

Table 2

Mean and Standard Deviations of Word Learning Measures by Book Format

	Production test[a]		*Definition test*[b]		*Comprehension test*[a]	
Book format	*M*	*SD*	*M*	*SD*	*M*	*SD*
Print	0.25	0.44	0.84	1.28	0.71	0.45
Digital	0.25	0.43	0.87	1.41	0.73	0.44

[a] binary outcome (0 incorrect, 1 correct. Range: 0 - 1)

[b] count outcome (number of meaningful units of information provided per each target word. No upper limit (range in the data: 0 - 7). Computed at the item (single word) level.

Table 3

Means, Standard Deviations, Range, and Correlations with Confidence Intervals of Vocabulary Knowledge, Executive Functions, and Word Learning Measures

Variable	*M*	*SD*	*Min*	*Max*	1	2	3	4
1. Vocabulary knowledge	10.13	2.82	1.00	16.00				
2. Executive functions	0.00	1.00	-2.46	2.79	.21 [.15, .28]			
3. Production test[a]	0.25	0.43	0.00	1.00	.09 [.02, .16]	.08 [.01, .15]		
4. Definition test[b]	0.86	1.35	0.00	7.00	.19 [.12, .26]	.12 [.04, .19]	.45 [.39, .51]	
5. Comprehension test[a]	0.72	0.45	0.00	1.00	.15 [.08, .22]	.08 [.01, .15]	.28 [.21, .34]	.23 [.16, .30]

Note. Min = minimum; Max = maximum. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014).

[a] binary outcome (0 incorrect, 1 correct)

[b] count outcome (number of meaningful units of information provided per each target word)

Confirmatory Analyses

Production test

Model results are reported in Table 4. The likelihood ratio test comparing the model including the test predictor of interest (M_1) with the model lacking the test predictor (M_0), indicated no significant main effect of book format on production scores ($\chi^2 = 1.295$, $df = 1$, $p = .25$). Similarly, the comparison of the model including the interaction between book format and child characteristics (M_2) with the model lacking these interaction terms (M_1), indicated no evidence of interactions between book format and child characteristics on production test ($\chi^2 = .803$, $df = 2$, $p = .67$). In sum, there was no evidence for any main or interaction effect of book format on production scores. There was evidence of a significant positive effect of knowledge of target words and vocabulary knowledge on production scores, as indicated by the positive sign of the respective coefficients.

Table 4

Results of the Models Estimating the Effect of Book Format, Child Characteristics, and Their Interaction, on Production test

	Production test											
	M_0				*M_1*				*M_2*			
Predictors	*Estimate*	*SE*	*CI*	*p*	*Estimate*	*SE*	*CI*	*p*	*Estimate*	*SE*	*CI*	*p*
(Intercept)	-4.39	0.51	-5.38 – -3.39	**<0.001**	-4.28	0.51	-5.29 – -3.28	**<0.001**	-4.61	0.65	-5.88 – -3.35	**<0.001**
Knowledge of target words	3.33	0.32	2.70 – 3.95	**<0.001**	3.34	0.31	2.72 – 3.95	**<0.001**	3.34	0.31	2.72 – 3.95	**<0.001**
Vocabulary knowledge	0.09	0.04	0.02 – 0.16	**0.012**	0.09	0.04	0.02 – 0.16	**0.012**	0.12	0.05	0.02 – 0.23	**0.018**
Executive functions	0.04	0.12	-0.19 – 0.27	0.751	0.04	0.12	-0.19 – 0.27	0.733	0.05	0.16	-0.26 – 0.35	0.772
Age	0.09	0.11	-0.12 – 0.31	0.393	0.09	0.11	-0.13 – 0.30	0.427	0.09	0.11	-0.12 – 0.31	0.409
Gender [M]	0.01	0.20	-0.38 – 0.40	0.961	0.01	0.20	-0.38 – 0.40	0.967	0.01	0.20	-0.38 – 0.40	0.954
Book format [digital]					-0.22	0.20	-0.60 – 0.16	0.255	0.42	0.77	-1.09 – 1.93	0.584
Book format [digital] × Vocabulary knowledge									-0.06	0.07	-0.20 – 0.08	0.391
Book format [digital] × Executive functions									-0.02	0.20	-0.42 – 0.38	0.937
Random Effects												

σ^2	3.29	3.29	3.29
τ_{00}	0.02 $_{child\_ID}$	0.02 $_{child\_ID}$	0.01 $_{child\_ID}$
τ_{11}	0.10 $_{child\_ID.book\_format.M}$	0.08 $_{child\_ID.book\_format.M}$	0.05 $_{child\_ID.book\_format.M}$
ρ_{01}	1.00 $_{child\_ID}$	1.00 $_{child\_ID}$	1.00 $_{child\_ID}$
ICC		0.00	0.00
N	99 $_{child\_ID}$	99 $_{child\_ID}$	99 $_{child\_ID}$
Observations	799	799	799
Marginal R^2 / Conditional R^2	0.468	0.467 / 0.470	0.469 / 0.470

1

Definition test

Model results are reported in Table 5. Similar to the production test, the likelihood ratio test comparing models M_1 and M_0 indicated no significant main effect of book format on definition scores (χ^2 = .470, *df* = 1, *p* = .49), and the likelihood ratio test comparing model M_2 with M_1 did not support the presence of significant interactions between book format and child characteristics on definition scores (χ^2 =4.015, *df* = 2, *p* =.13). There were significant positive main effects of knowledge of target words and also vocabulary knowledge on definition scores. Boys were significantly more accurate than girls. There was a significant positive main effect of executive functions on the definition scores.

Table 5

Results of the Models Estimating the Effect of Book Format, Child Characteristics, and Their Interaction, on Definition test

	Definition test											
	M_0				*M_1*				*M_2*			
Predictors	*Estimate*	*SE*	*CI*	*p*	*Estimate*	*SE*	*CI*	*p*	*Estimate*	*SE*	*CI*	*p*
(Intercept)	-2.84	0.36	-3.54 – -2.13	**<0.001**	-2.79	0.37	-3.51 – -2.07	**<0.001**	-3.07	0.46	-3.96 – -2.17	**<0.001**
Knowledge of target words	1.37	0.11	1.15 – 1.58	**<0.001**	1.37	0.11	1.15 – 1.58	**<0.001**	1.37	0.11	1.15 – 1.58	**<0.001**
Vocabulary knowledge	0.12	0.03	0.06 – 0.18	**<0.001**	0.12	0.03	0.06 – 0.18	**<0.001**	0.15	0.04	0.07 – 0.23	**<0.001**
Executive functions	0.19	0.10	0.00 – 0.38	**0.048**	0.19	0.10	-0.00 – 0.38	0.051	0.08	0.11	-0.14 – 0.30	0.491
Age	0.06	0.09	-0.12 – 0.23	0.532	0.05	0.09	-0.13 – 0.23	0.569	0.05	0.09	-0.13 – 0.22	0.609
Gender [M]	0.34	0.16	0.02 – 0.65	**0.039**	0.33	0.16	0.02 – 0.65	**0.040**	0.34	0.16	0.02 – 0.66	**0.035**
Book format [digital]					-0.11	0.16	-0.41 – 0.20	0.495	0.51	0.61	-0.68 – 1.70	0.400
Book format [digital] × Vocabulary knowledge									-0.06	0.05	-0.17 – 0.04	0.241
Book format [digital] × Executive functions									0.27	0.16	-0.04 – 0.57	0.087

Random Effects

σ^2	0.99	0.99	0.99
τ_{00}	0.34 $_{child\_ID}$	0.35 $_{child\_ID}$	0.35 $_{child\_ID}$
τ_{11}	0.85 $_{child\_ID.book\_format.M}$	0.86 $_{child\_ID.book\_format.M}$	0.85 $_{child\_ID.book\_format.M}$
ρ_{01}	0.11 $_{child\_ID}$	0.17 $_{child\_ID}$	0.20 $_{child\_ID}$
ICC	0.26	0.26	0.26
N	94 $_{child\_ID}$	94 $_{child\_ID}$	94 $_{child\_ID}$
Observations	669	669	669
Marginal R^2 / Conditional R^2	0.345 / 0.513	0.343 / 0.514	0.350 / 0.518

1

Comprehension test

The effect of book format on comprehension test was examined using the same model fitting process and comparison as before. Model results are reported in Table 6. The likelihood ratio test indicated no significant main effect of book format on comprehension scores (χ^2 = .134, *df* = 1, *p* = .72). The interaction model was not a significantly better fit to the data (χ^2 = 3.930, *df* = 2, *p* =.14). However, the coefficients of the interaction model (M_2) supported the presence of a significant interaction between book format and executive functions (Table 6).

To inform our interpretation, we pruned the nonsignificant interaction between book format and vocabulary in a follow-up model (M_3). We then contrasted the model containing only the interaction between book format and executive functions (M_3) against a model lacking this term but being otherwise identical (M_1). The results of the likelihood ratio test supported the presence of a significant interaction between book format and executive functions (χ^2 = 3.98, *df* = 1, *p* < .05). Further, the coefficients of M_3 confirmed the presence of a significant interaction between book format and executive functions as well as main effects of vocabulary and gender (see Table S5, Supplementary Materials). In sum, there was evidence that book format interacted with executive functions, but not with vocabulary knowledge, for comprehension scores.

Table 6

Results of the Models Estimating the Effect of Book Format, Child Characteristics, and Their Interaction, on the Comprehension test

	Comprehension test											
	M_0				*M_1*				*M_2*			
Predictors	*Estimate*	*SE*	*CI*	*p*	*Estimate*	*SE*	*CI*	*p*	*Estimate*	*SE*	*CI*	*p*
(Intercept)	-1.03	0.44	-1.89 – -0.17	**0.018**	-1.07	0.45	-1.95 – -0.19	**0.017**	-1.06	0.53	-2.09 – -0.03	**0.043**
Knowledge of target words	1.27	0.20	0.87 – 1.67	**<0.001**	1.26	0.20	0.86 – 1.67	**<0.001**	1.17	0.19	0.80 – 1.53	**<0.001**
Vocabulary knowledge	0.13	0.04	0.05 – 0.21	**0.001**	0.13	0.04	0.05 – 0.21	**0.001**	0.13	0.05	0.04 – 0.23	**0.007**
Executive functions	0.20	0.13	-0.06 – 0.46	0.141	0.19	0.13	-0.07 – 0.45	0.145	0.03	0.15	-0.27 – 0.33	0.839
Age	-0.14	0.13	-0.39 – 0.11	0.281	-0.14	0.13	-0.39 – 0.11	0.276	-0.13	0.12	-0.37 – 0.11	0.278
Gender [M]	0.52	0.23	0.06 – 0.97	**0.025**	0.52	0.23	0.07 – 0.97	**0.024**	0.50	0.22	0.06 – 0.94	**0.025**
Book format [digital]					0.08	0.21	-0.34 – 0.49	0.717	0.22	0.64	-1.03 – 1.46	0.733
Book format [digital] × Vocabulary									-0.01	0.06	-0.13 – 0.11	0.834
Book format [digital] × Executive functions									0.34	0.17	0.00 – 0.69	**0.050**

Random Effects

σ^2	3.29	3.29	3.29
τ_{00}	0.37 $_{child\_ID}$	0.37 $_{child\_ID}$	0.32 $_{child\_ID}$
τ_{11}	0.83 $_{child\_ID.book\_format.M}$	0.82 $_{child\_ID.book\_format.M}$	
ρ_{01}	0.10 $_{child\_ID}$	0.15 $_{child\_ID}$	
ICC	0.10	0.10	0.09
N	99 $_{child\_ID}$	99 $_{child\_ID}$	99 $_{child\_ID}$
Observations	794	794	794
Marginal R^2 / Conditional R^2	0.160 / 0.245	0.161 / 0.245	0.152 / 0.228

1

Figure 1

Note. Figure 1 illustrates predicted (fitted lines) and observed values (dots) values of the word comprehension test by A) vocabulary knowledge and B) executive functions, across book formats (colour coded).

To guide interpretation of the interaction, predicted probability plots are shown in Figure 1. For children with higher executive function skills, digital-based shared reading had a positive effect on comprehension scores compared to print-based shared reading, while the opposite was true for children with lower executive functions. Looking at this interaction from another perspective, the effect of executive functions on comprehension scores was stronger in the digital condition, compared to the print condition, while vocabulary was a strong determinant of comprehension scores across both book formats.

We note that there was a significant positive main effect of knowledge of target words and vocabulary knowledge on the comprehension scores, as indicated by the positive sign of the respective coefficient. Furthermore, boys were significantly more accurate than girls in the comprehension test.

Discussion

The present study examined the effects of book format (print vs. digital) and individual differences in vocabulary knowledge and executive functions on children's word learning from naturalistic shared book reading with a caregiver. Book format influenced only certain aspects of word learning, and this was conditional on child characteristics. In the digital book condition only, higher comprehension scores were obtained by children who scored more highly on the measures of executive functions. Children with greater prior vocabulary knowledge were significantly more accurate across word learning measures, whereas executive functions uniquely contributed to scores on the definition test. Boys were significantly more accurate than girls in both the definition and comprehension tests. We discuss each of these findings and their implications for theory and practice.

We did not find evidence of a main effect of book format on word learning from shared reading in young children. However, for the comprehension test, there was evidence that book format interacted with executive functions. This effect might be explained by the prior experience children bring to the task. Digital devices serve purposes other than shared reading (e.g., streaming, playing) and are operated in various ways (e.g., tapping, swiping, scrolling). It has been proposed that operating touchscreens might tax the young child's executive functions and diminish learning (Courage, 2019). While the adult caregiver led the shared reading interaction in our study, it is possible that children with immature executive functions were more susceptible to distractions associated with operating a touchscreen.

On the other hand, it is important to note that children with higher executive functions benefitted from the digital format in our study. This suggests that once executive functions are sufficiently developed, the digital format may bring some advantages. A possible explanation for such an advantage can be the relative novelty of digital-based shared reading (see Table S1, Supplementary Materials). This novelty may have boosted children's interest

in the activity and, in turn, learning (Flewitt et al., 2015; O'Toole & Kannass, 2018). Prior research indeed suggests that children who rarely use a tablet, learn more from the digital format, but the opposite is true for weekly tablet users (Reich et al., 2019). Further investigation is needed to test the generalisability of these findings to different cultural contexts, especially considering that these results may vary as a function of experience with digital media. The interaction between executive functions and book format supports the notion that learning is shaped by the interplay between characteristics of the learning material and the learner, as proposed by the dynamic system framework and media-specific models (Fisch, 2000; Thelen & Smith, 1994; Valkenburg & Peter, 2013). Furthermore, these findings informed the formulation of a recent model of scaffolding and individuality, which emphasises the need to take into account different elements in the scaffolding process, including possible interactions between inter-individual differences and properties of the scaffold (Carranza-Pinedo & Diprossimo, 2025). This demonstrates the broader reach and implications of the current findings.

There was a significant and positive main effect of vocabulary knowledge on word learning for all word learning measures, which is in line with prior research (Sénéchal et al., 1995). Thus, regardless of format, vocabulary was an important determinant of word learning from shared reading. Children with a larger vocabulary learned new words more easily, likely because extant vocabulary is an index of word learning skills. Prior work has indeed shown that standardised assessments of prior vocabulary relate to word learning in experimental tasks (e.g., Gathercole et al., 1997). In older children, vocabulary knowledge is associated with reading comprehension and also with the ability to learn new words presented in story contexts (Cain et al., 2004). Further, children's existing knowledge base and category knowledge have been shown to facilitate the acquisition of new words in younger children (Borovsky et al., 2016). A potential implication of these findings is that children with a larger

vocabulary will continue learning new words more and more efficiently over time, resulting in increasingly wider word gaps between children. This notion relates to the so-called Matthew Effects, referring to rich-get-richer and poor-get-poorer processes, which have been proposed to explain emerging differences in language ability over time (Stanovich, 1986).

In line with prior research on pre-school children (Hadley et al., 2021; Kapa & Erikson, 2020), executive functions predicted performance on the definition test after controlling for vocabulary knowledge. This supports the view that higher-level cognitive functions are particularly important in the acquisition of word meanings as assessed with a definition task. This also aligns with findings on word learning from written context in school-aged children (Cain et al., 2004).

An unexpected finding was that boys outperformed girls on two of the three word-learning measures: the definition and comprehension tests. Girls typically outperform boys on language and literacy development measures (Eriksson et al., 2012; Frank et al., 2017; Logan & Johnston, 2010), an effect that is small, but reliably found across cultural contexts (Eriksson et al., 2012). However, some researchers have pointed to the importance of understanding in which specific contexts gender differences are observed (Bergman Deitcher et al., 2019; Logan & Johnston, 2010). For instance, it has been shown that boys outperform girls in word learning from shared reading of informational, but not narrative, texts (Bergman Deitcher et al., 2019). Boys in our sample were not significantly older, nor had higher verbal ability or executive functions. To explore possible sources of gender differences, we conducted descriptive analyses of caregiver scaffolding and child engagement for the subsample of participants that provided codable video recordings of the shared reading session (n = 78). There were no apparent gender differences in caregiver scaffolding and child engagement (see Figure S1 and S2, Supplementary Materials). We also explored whether the superordinate category of target words (animals vs. tools) might be driving the

observed gender differences, however, this was not the case (see Table S4, Supplementary Materials).

Limitations and future directions

In addition to the limitations already discussed, we note the most pertinent here. A strength of our study was the inclusion of multiple measures of executive functions, which allowed a comprehensive sampling of this construct. However, a potential limitation is that we did not examine the influence of separate executive function components on word learning. However, our measures loaded onto a single factor, and exploration of the individual measures indicated similar relations between individual measures of executive functions and word learning across book formats (see Figure S2, S3, S4, S5 in the Supplementary Materials).

Finally, to enable comparison between print and digital shared reading conditions, we did not include interactive features in our digital books. This control may account for why we did not find strong effects of book format across the word-learning measures. However, it is important to point out that the affordances of digital books open up new opportunities to scaffold understanding and learning. Future work should investigate how e-book features may be designed to support parental mediation during shared reading (Troseth et al., 2020). This might be usefully informed by research on the role of built-in scaffolds to support comprehension and word learning during independent reading in beginning readers (Diprossimo et al., 2023).

Conclusions

Shared book reading provides unique opportunities to boost children's vocabulary knowledge, which lays the foundation for later educational and social outcomes. Our findings provide the first empirical evidence for an interaction between book format and executive functions, suggesting that the effect of book format is not the same for all children. In the

changing landscape of early literacy practice, this study underscores the importance of considering individual differences and multiple outcomes when studying learning from different media.

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