Title: Reading Print vs. on Screen: How Do Medium and Text Structure Influence the Ability To Locate Information in Text?

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Statements and Declarations

The authors have no competing interests to declare that are relevant to the content of this article.

Ethics approval

The Ethics Committee for Research in Humanities and Social Sciences of the University of Latvia approved the study (project number: 30-95/3).

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Reading Print vs. on Screen: How Do Medium and Text Structure Influence the Ability To Locate Information in Text?

Abstract

As readers process text, they not only construct a mental representation of its meaning, but also encode the spatial location of words or sections of the text that convey essential information. The current study investigated the effects of reading medium (print vs. digital) and text structure (linear vs. hierarchical) on the ability to recall the location of information in expository texts and examined performance in relation to comprehension of the text, and independent measures of spatial working memory and reading habits. Participants were 128 students (64 female) from grades 4 to 6 in Germany. Accuracy of recall of the location of information was high in both media, but significantly poorer in the digital medium. This effect was not influenced by text structure or comprehension of the text. Spatial working memory was significantly and positively related to recall of the location of information, but frequency of reading non-fiction, comics and blogs in the digital medium was significantly and negatively associated with the recall of information location.

Keywords: Reading print vs. digital, expository text, spatial working memory, young readers

When processing a text, readers not only construct a mental representation of its meaning (Kintsch, 1998), but they also encode the spatial location of words or sections of text containing key information (Le Bigot et al., 2011; Payne & Reader, 2006). In this way, both the content and the spatial layout of the text are encoded into a mental representation (Johansson et al., 2018; Kennedy et al., 2003). Memory for the location of information may enable readers to revisit complex or ambiguous text to check and retrieve critical information (Inhoff & Weger, 2005; O'Hara et al., 1999), or to resolve comprehension difficulties. This can aid learning from texts and contribute to improved performance on assessments (Bråten et al., 2013; Rawson et al., 2000). This study adds to the scant research base on young readers' memory for the location of key textual information and its relation to memory for content (Cataldo & Oakhill, 2000). It compares, for the first time, the relation between location and content memory across different media (print vs. screen reading). This study further advances knowledge by exploring the relation between spatial working memory, reading habits and digital device use on recall of the location of critical textual information.

The Relation Between Content Representation and Visuospatial Representation

Readers construct a mental representation of a text's content by integrating propositions derived from the text (Kintsch, 1998). While traditional theories of reading focus on text and reader characteristics that influence the construction of the meaning-based representation of a text, the influence of surface-level elements such as the spatial arrangement of information has not received much attention. However, there is evidence that readers map the content of a text onto its spatial layout and can reactivate this visuospatial representation when recalling information from the text (Johansson et al., 2018; Kennedy et al., 2003; Le Bigot et al., 2011; Richardson & Spivey, 2000). For instance, after reading a sentence on a computer screen, adult

readers can accurately point to where on the screen specific words were displayed (Zechmeister et al., 1975). Adult readers' eye movements are efficient when having to retrieve already read words, without needing to reread the entire passage (Inhoff & Weger, 2005), and gaze patterns show that readers reactivate a representation of the visuospatial arrangement of the text when retelling its content (Johansson et al., 2018). Critically, adult readers' recall of content and its location are related in both the print (Lovelace & Southall, 1983; Rothkopf, 1971; Zechmeister et al., 1975) and digital medium (Rawson & Miyake, 2002). Notably, these studies did not instruct readers to focus and process the location of information in their initial reading of the text, indicating that location coding occurs incidentally as part of the reading process.

Despite the evidence that location encoding occurs incidentally when reading (Inhoff & Weger, 2005; O'Hara et al., 1999; Payne & Reader, 2006; Rothkopf, 1971), the strength of the association between memory for content and location encoding may be task dependent. For instance, in their study of a 12-page digital text, Rawson and Miyake (2002) found a relationship between memory for location of information (measured by recall of the sentence location) and memory for content. Similarly, in a study of print reading, Therriault and Raney (2002) found that comprehension was associated with performance on a text-sequencing task, in which participants indicated the quartile of the text containing the answer to a comprehension question. However, Therriault and Raney (2002) found that a more precise measure of recall of the location of information - place on the page - was not related to comprehension scores. The discrepancy in findings between measures could be attributed to differences in task granularity as the text-sequencing task may provide a less precise assessment of the recall of the location of critical information. Another explanation might be that readers do not construct a precise spatial representation of location of information relative to their representation of content. Clearly, the

relationship between reading comprehension and the ability to recall the location of key information requires further investigation.

Only one study to date has explored the relation between memory and comprehension of text and recall of the location of critical information in young readers, and that study examined reading of print only (e.g., Cataldo & Oakhill, 2000). Students in grade 5 who had been categorised as good or poor comprehenders performed similarly in remembering the location of key words, but the efficiency of their search behaviour differed. Whereas good comprehenders often directly accessed relevant information, poor comprehenders engaged in undirected search behaviour, resulting in longer search times. Both recall and comprehension of the story were positively associated to search efficiency. This study shows a relation between memory for the location of information and content when reading print.

Remembering where key information is located helps reader revisit text passages and extract necessary details (O'Hara et al., 1999; Payne & Reader, 2006). Efficient search and retrieval facilitate an important comprehension strategy, namely rereading. Rereading helps readers address comprehension difficulties and has been shown to aid comprehension in adults (Rawson et al., 2000) and children (Bossert & Schwantes, 1995). Indeed, skilled readers often backtrack to earlier text sections when they encounter new information (Pressley & Afflerbach, 1995), thereby updating their mental representation of text (van Dijk & Kintsch, 1983). In digital environments this strategic backtracking has been found to contribute to comprehension of expository text in adults (Haverkamp & Bråten, 2022) and across multiple digital texts in young readers (Bråten et al., 2013). As text structure and content become more complex, particularly in the later elementary grades and into secondary school when readers transition from learning to

read to reading to learn (Chall, 1983), rereading may play an increasingly prominent role (Denton et al., 2015).

Reading Print versus on Screen

In recent years, numerous studies have contrasted comprehension of print and digital media (see Clinton, 2019; Delgado et al., 2018; Kong et al., 2018 for reviews), finding lower reading comprehension for text read on screen compared to print. Reading print, with its fixed layout constrained by page borders, provides easily accessible information about text organisation, such as length and paragraph structure (Mangen & Kuiken, 2014). This, in turn, might facilitate encoding of the location of key information and aid readers to construct an accurate and coherent mental representation of the text's meaning. In contrast, reading on digital devices such as computers, tablets, or smartphones presents unique challenges due to the absence of clear orientational cues, such as page breaks, and the need to scroll, which results in no fixed location on screen for critical information.

Indeed, readers have reported difficulties forming a representation of the entire text and accurately locating information in digital texts (Rose, 2011). This is supported by a study of adult readers by Piolat et al. (1997) who observed that page-by-page presentation of digital text led to better recall of the location of information than when participants had to scroll. Moreover, text comprehension was also inferior in the scrolling condition, suggesting that page borders and the specific location of information on screen in the page-by-page presentation format served as retrieval cues for both content and information location. Similarly, adult digital readers displayed more strategic backtracking and better integrated understanding when paging than when scrolling (Haverkamp et al., 2023). This indicates that the paging format may facilitate backtracking, which requires awareness of where information is located.

Few studies have examined how different presentation modalities influence recall of the location of information and its relation to reading comprehension. A notable exception is the study of adult readers by Mangen et al. (2019), who compared comprehension of a long narrative mystery story read in a print book and on an e-book device. Recall of content did not differ between the two media. However, print readers were better at reconstructing the plot (arranging events according to event sequence), indicating better representation of the chronological and temporal dimensions of the text. Overall, the two groups did not differ significantly in their ability to recall the location of information, but print readers outperformed their digital counterparts in recalling the location of events at the beginning of the story, suggesting a more detailed and robust visuospatial representation of the text. Moreover, there was a close relationship between the ability to reconstruct the plot and accuracy of recalling the location of information.

Text Structure, Event Order, and their Relation to Memory for the Location of Information

The way that information is structured in a text influences how it is processed and remembered (Ohtsuka & Brewer, 1992; Zwaan & Radvansky, 1998). For instance, Ohtsuka and Brewer (1992) found that the order in which the events were presented in the text (text structure) influenced readers' ability to accurately reproduce the chronological order of events. Specifically, when the chronological order of events closely aligned with the text structure, participants demonstrated higher accuracy in judging the correct chronological order compared to texts with flashback and flashforward passages (Ohtsuka & Brewer, 1992).

Linear texts are characterised by chronological ordering of events and, therefore, there is a close relationship between the location of information and the sequence of events. Given the close association between memory for the location of information and the reader's representation

of text content (Le Bigot et al., 2011; Rawson & Miyake, 2002), it is conceivable that the close alignment of text structure and the underlying event sequence might facilitate the encoding and recall of information location. There is evidence from an eye tracking study to support this view. Johansson et al. (2018) found that when adult readers retold a previously read story, they were more likely to fixate on the correct location when the text layout mirrored the structure of the described scene. These findings suggest that text structure can impact the reactivation of a readers' visuospatial representation of the text. In contrast, texts featuring description of concepts, definitions, relations, and causal chains adopt a hierarchical text structure and lack this close alignment between text structure and event sequence (Mandler, 1986). In such texts, passages or idea units are to some degree interchangeable in their order of presentation, and the representation of the text's meaning may not be closely linked to a visuospatial representation of the text content layout, potentially leading to poorer encoding and memory of the location of information. We address this gap in the literature and examined the impact of text structure on the recall of the location of specific content.

Spatial Working Memory and its Relation to the Recall of the Location of Information

Of relevance to this study is the role of working memory, specifically visuospatial skills, and text comprehension. Working memory is related to children's reading comprehension in general (Cain et al., 2004) and, for adults, there is evidence that the ability to locate information depends on visuo-spatial information processing (Zechmeister et al., 1975). Indeed, Le Bigot et al. (2009) found that recall of location of words was disrupted when writers performed a visuospatial concurrent task during composition, indicating the involvement of visuospatial processes in encoding word location. Consequently, readers with higher visuospatial abilities might have an advantage in encoding and recalling the spatial layout of the text. Given the

potential influence of visuospatial skills, we explore the relation between spatial working memory and recall of the location of information in the current study.

Reading Habits and Their Influence on Recall of the Location of Information

Frequency of leisure-time reading is positively associated with reading skills (Cipielewski & Stanovich, 1992; Mol & Bus, 2011). Given the different features of print and digital media, familiarity with each might influence performance on tasks related to recall of the location of information. As noted, the print format features hard page boundaries, whereas digital presentation can either involve hard page boundaries (as with e-readers) or scrolling (as with web presentation). Adults demonstrate better recall of the location of information when digital texts are presented and navigated by paging, rather than scrolling (Piolat et al., 1997). However, readers who are used to reading digitally might have developed strategies to mitigate challenges that arise from digital presentation, including the fluid nature of the spatial layout of texts and the absence of a fixed location for information on the screen, due to scrolling. The impact of digital reading habits and familiarity with digital devices on the recall of the location of information in digital texts, particularly in young readers, has not been explored to date.

The Current Study

This study investigated whether the ability to recall the location of information in text is influenced by medium (print vs. digital) and structure of different expository texts (linear vs. hierarchical structure) in young readers. This is the first study to directly contrast recall of the location of information for print and digital in this age group. Our research questions and hypotheses are outlined below. As there is no existing research on this topic in children, our predictions were based on findings from studies with adults.

1. Does the ability to recall the location of information in expository text differ between print and digital media? We hypothesised that participants in the print medium should be better at recalling the location of information, compared to those in the digital medium, in line with studies of adults (Piolat et al., 1997).
2. How does the structure of expository texts (linear vs. hierarchical) influence recall of information location? In linear texts, the sequence of information aligns with the chronological order of events. Thus, we predicted that participants would recall information locations more accurately in text with a linear than hierarchical text structure, as found for adults (Ohtsuka & Brewer, 1992).
3. What is the relationship between reading comprehension and the ability to recall the location of information? We expected the ability to recall the location of information to be positively related to comprehension of the text (Rawson & Miyake, 2002).
4. How does spatial working memory influence the ability to recall the location of information? We explored the relationship between spatial working memory and ability to locate information, based on evidence that visuospatial processes are involved in encoding of the location of words (Le Bigot et al., 2009).
5. How do digital reading habits relate to the ability to recall the location of information? There have been no studies investigating this relationship. However, experienced digital readers may have developed strategies to mitigate the challenges of digital reading, thus we hypothesised a relationship between leisure-time digital reading and recall.

Our study employed a mixed design, incorporating both between-subject (medium) and within-subject (text structure) factors, controlling for word recognition, gender, age and testing

location (school vs. lab). We controlled for word recognition because readers with stronger word recognition can allocate more cognitive resources to comprehension processes (Perfetti, 1985), potentially enhancing incidental memory for the location of key information. We controlled for gender differences because previous research reported gender differences in digital reading habits (Hu et al., 2024). The study design, questions, and analytic methods were pre-registered on the Open Science Framework at https://osf.io/6gmeu?view_only=d11bb2c613334f01a070c60f364c5df4.

Methods

Participants

Participants were 128 children in grades 4 to 6, recruited from a database and one primary and two secondary schools in Germany. Participants with a known learning difficulty, such as dyslexia, were not enrolled in the study. Caregivers provided signed consent, and participation was rewarded with a book and educational game. The Ethics Committee for Research in Humanities and Social Sciences of the [REDACTED FOR REVIEW] approved the study. See Table 1 for the sample composition.

Table 1

Sample Composition

	Medium	N	Females N/%	Age in months Mean (SD)	Tested in school N/%
Total	Print	66	33/50	129.45 (10.82)	19/29
	Digital	62	31/50	130.76 (11.13)	16/26
Grade 4	Print	19	11/58	115.68 (3.33)	4/21
	Digital	18	11/61	116.89 (5.35)	1/5
Grade 5	Print	23	10/43	129.70 (5.12)	4/17
	Digital	24	11/46	132.83 (7.12)	8/33
Grade 6	Print	24	12/50	140.12 (4.66)	11/46
	Digital	20	9/45	140.75 (4.22)	7/35

Note. Percentages represent the proportion of participants within each combination of grade and medium.

Materials

Across two conditions (print vs. digital), participants read two texts which differed both in text structure (linear vs. hierarchical) and content (history vs. palaeontology). The linear text (history) was characterised by the chronological presentation of events. The hierarchical text (palaeontology) introduced different concepts and definitions, made comparisons among them, and highlighted their relationships. The text analysis tools RATTE (Regensburger Analysetool für Texte; Wild & Pissarek, n.d.) and Coh-Metrix[1] (Graesser et al., 2004) were used to compare the two texts. While linear texts typically feature more indicators of temporality to describe the sequence of events, hierarchical texts include more causal verbs to connect ideas and show relationships between concepts (Meyer & Ray, 2011), as reflected in different scores for these

[1] The text analysis tool Coh-Metrix is currently only available for English. Machine-translated versions of the German texts (edited by the first author) were used for analysis and need to be considered when interpreting the metrics.

dimensions (see Table 2). Critically, the texts did not differ in syntactic complexity, word count, and word familiarity.

Table 2

Linguistic Features of the Linear and Hierarchical Text

RATTE	Measure	Linear text structure	Hierarchical text structure
	Word count	392	375
	Average words per sentence	15.77	14.62
	Word familiarity: words in the 25% rarest category	29	24
	Readability	38.61 (suitable for grade 4-5)	44.73 (suitable for grade 4-5)
Coh-Metrix			
	Syntactic simplicity: Argument overlap	0.47	0.43
	Syntactic complexity: mean number of words before the main verb	4.00	4.04
	Incidence of causal verbs	37.12	46.39
	Temporality (percentile)	86.21	34.46

Design

This study had a mixed design, combining within-subject and between-subject factors. Text structure was manipulated within participant: Each participant read two texts, one linear and one hierarchical. Medium was manipulated across participants: Each participant read texts in only one format - either print (on paper) or digital (on a PC). Within each grade level, participants were randomly allocated to either the print or digital medium, while maintaining a balanced gender distribution. The presentation order of the linear and hierarchical text was counterbalanced.

Measures

Reading Comprehension

Each participant was presented with the two texts either in the print (two A4 pages for each text) or digital medium (presented on a computer screen, where participants had to scroll to see the entirety of the text, simulating typical digital reading). The digital texts extended across two screens and were presented in Fira Sans, 12pt. Participants could not change font size. In the print condition, margins were set to 2.54 cm (1 in) at the top and bottom, and 5 cm (1.97 in) on the left and right. In the digital condition, the margins remained the same at the top and bottom and on the left, but the right margin was wider at 7 cm (2.76 in). Participants were instructed to read the texts and answer questions about each one. They were not given any specific instruction to remember the location of key information. Reading time was unrestricted in both conditions and participants could not revisit the text after completing it. After reading each text, participants answered six multiple choice comprehension questions. For each question, there were four answer options, of which only one was correct. Each response was recorded as either correct or incorrect. Excerpts from the text and example questions are provided in Supplementary Materials. The questions were presented in randomised order to ensure a valid assessment of recall of location of information (see next section), avoiding potential bias from question order which could inadvertently suggest the location of key information.

Recall of Location of Information

After each comprehension question, participants were asked to indicate the location of the information needed to answer the question. For this purpose, participants were presented with a rectangle representing the spatial layout of the text, with black lines drawn symbolising sentences (cf. Rothkopf, 1971). We used this measure because it aligns with methods employed

in prior research on the topic with adults (Mangen et al., 2019; O'Hara et al., 1999; Ohtsuka & Brewer, 1992; Rothkopf, 1971). In the digital medium, the rectangle was divided into eight fields from top to bottom, reflecting the entire digital text. In the print medium, two rectangles represented one A4 page and were divided into four fields, respectively, emulating the spatial structure of the print texts. Each field was marked in ascending order with a number between 1 and 8. Participants were asked to insert the number corresponding to the location where the information to answer the question could be found. For some items, the correct answer was found in two adjacent locations, for example in sections 2 and 3. Therefore, participants were allowed to insert a maximum of two numbers in their response.

An error score, calculated as the absolute value of the difference between correct location minus location indicated by the participant, was computed. If the correct answer was found in two locations, both solutions were subtracted from the indicated location, and the lower error score was chosen. Participants were able to indicate their responses by choosing numbers between 1 and 8, representing possible sentence or paragraph positions. This resulted in an error score range of 0 to 7, with lower scores indicating greater accuracy in recalling the location of information. Invalid answers, such as entering more than two numbers, numbers greater than 8, or entering invalid responses such as letters, were excluded from the analysis. The assessment method to evaluate the ability to recall the location of information allowed for multiple scoring approaches; an alternative scoring approach and corresponding analysis results are reported in Supplementary Materials.

Word Recognition

A silent test of word recognition, a time-limited version of the Word Chain Test (Jacobson, 1995; Scorza et al., 2019), was used to measure word recognition. The test was

presented on a computer. On a single screen, participants saw ten chains, each comprising five words (e.g. MAUSBLAUKRANKSCHWANFISCH; engl. transl. of words: mouse-blue-ill-swan-fish). They were instructed to separate as many words as possible, in a minute, by clicking in the appropriate place with the computer mouse. The words were taken from the SLRT (Salzburger Lese- und Rechtschreibttest; Salzburg reading and spelling test; Landerl et al., 1997). One point was awarded for each correctly separated word. As participants were not able to delete lines they placed mistakenly, there was no penalty for errors.

Spatial Working Memory

The symmetry span task (Kane et al., 2004) was used to measure spatial working memory. Participants were required to remember the order of red square positions presented to them in a 4X4 grid. After each red square, participants performed a distractor task by determining whether a black-and-white block pattern was symmetrical. There were two practice trials with a sequence of two red squares. Experimental trials required participants to recall sequences of three to six red squares in ascending order. The final score was the total number of correctly recalled positions in order.

Reading Habits and Digital Exposure

Participants completed a questionnaire about print and digital reading habits and the availability and use of digital devices, such as computers, tablets, and smartphones. Participants rated their frequency of use on a 5-point Likert scale ranging from “Almost never” to “Several times a day”. A factor analysis performed on the items of the reading habits and digital device use questionnaire ([REDACTED FOR REVIEW], in preparation) identified four distinct factors: “Print reading” (encompassing fiction, non-fiction, magazines, and comics in the print medium), “Digital fiction reading” (encompassing fiction and use of e-book readers), “Digital mixed genre

reading" (non-fiction, blogs, and comics) and "Leisure activities on smartphone" (smartphone use for games, social media, and YouTube videos). We used the factor scores of the last three to examine the relationship between digital reading habits device usage and the ability to recall information location in digital text.

Analysis

The response of interest (accuracy in recalling the location of information) was ordinal in nature; the error score ranged from 0 (indicating that location identified by the participant matched actual location) to 7 (maximum error score). Therefore, an ordinal logistic regression model with cumulative logit link function was chosen (McCullagh & Nelder, 1989). To estimate the extent to which accuracy of recall of the location of information differed between media (print, digital), and varied with reading comprehension and text structure (linear, hierarchical), we fitted an ordinal (i.e., cumulative logit link) generalised linear mixed effects model (GLMM; Agresti, 2007), starting with the maximal random effects structure (Barr et al., 2013). We controlled for word recognition, testing location (school vs. lab), gender, and age in our analysis. Further, we accounted for presentation order because participants were not instructed to remember the location of key information, but when presented with the second text, it was evident that this would be required.

Prior to fitting the model, we releveled the response (error score) so that lower levels corresponded to higher error scores, indicating lower accuracy. This ensures that a negative coefficient reflects a negative influence on accuracy. Computed variance inflation factors of maximum 1.4 indicated that collinearity was not an issue (cf. Zuur et al., 2010). We conducted a full-null-model-comparison to mitigate the risk of "cryptic multiple testing" (Forstmeier &

Schielzeth, 2011) employing a Likelihood ratio test (Dobson, 2002), which revealed that the full model was significantly different from the null model (χ^2= 9.74, *df*=2, p<0.05).

Results

Data from 128 participants from grades 4 to 6 were collected. Due to invalid entries in the location recall measure, such as inputting all numbers (1 to 8) or letters, a total of 42 individual observations across 9 different participants were excluded. These exclusions affected only specific observations, so the full sample (*N* =128 participants) was retained with a total of 1,477 observations for statistical analysis. None of the comparisons between the print and digital groups (word recognition, spatial working memory, age, and factor scores) reached conventional levels of statistical significance ($p < .05$). See Table 3 for the descriptive statistics of participant variables.

Table 3

Descriptive Statistics for Participant Variables

Measure	Print Mean (SD)	Digital Mean (SD)	Mean difference analysis (t-test)
Word recognition	16.73 (6.99)	16.64 (6.37)	t = 0.20, df = 125.89, p = 0.98
Spatial working memory	18.02 (9.25)	19.45 (9.18)	t = -0.93, df = 125.68, p = 0.36
Age (in months)	129.52 (10.70)	130.98 (10.89)	t = -0.67, df = 124.97, p = 0.50
Factor Print reading	9.19 (3.54)	9.94 (3.53)	t = 3.86, df =108, p = 0.24
Factor Digital Fiction Reading	2.39 (1.04)	2.53 (1.41)	t = 0.61, df = 108, p = 0.54
Factor Digital mixed genre reading	3.39 (1.01)	4.04 (2.13)	t = 1.95, df = 108, p = 0.05
Leisure activities on smartphones	9.49 (4.04)	10.47 (4.70)	t = 1.05, df = 108, p = 0.30

Table 4

Recall of Location of Information and Reading Comprehension per Medium and Text Structure

Measure	Print Mean (SD)		Digital Mean (SD)	
	Linear	Hierarchical	Linear	Hierarchical
Location of information (Error score)	0.94 (0.70)	0.98 (0.72)	1.12 (0.66)	1.48 (0.75)
Comprehension (Proportion correct)	0.73 (0.24)	0.67 (0.25)	0.64 (0.28)	0.59 (0.24)

Note. The error score was calculated as the absolute value of the difference between correct location minus location indicated by the participant, the higher the value, the higher the error.

Table 4 shows accuracy of recall of the location of information and reading comprehension. Accuracy on location recall and reading comprehension were both higher in the print than digital medium. To assess whether participants performed above chance level, the error score was transformed into a binary score (correct/incorrect exact location). Even with this stricter operationalisation of accuracy, participants performed above chance (0.47 in our sample versus 0.30 chance level[2]).

Correlations between all variables are reported in Table 5. As the error score ranged from 0 to 7, with higher values reflecting lower accuracy, the correlations to the recall of location of information measure were reversed multiplying them by -1, ensuring that a positive correlation reflects higher performance in both measures.

[2] For questions with one correct answer, the probability of success was 1/8 and for questions with two correct answers, the probability was $1-(6/8\times5/7)$. Chance level performance = $(6 \times 6/8 + 6 \times 5/7)/12 = 3.54/12 = 0.30$ or 30%. Details in Supplementary Materials.

Table 5

Correlation Table of Variables in the Print and Digital Medium (N = 66 in the Print and N = 62 in the Digital Medium)

Variable	1	2	3	4	5	6	7	8	9
1. Recall of location of information (error score per participant)	---	0.53***	0.03	0.24	0.07	0.03	0.13	-0.20	-0.11
2. Comprehension (proportion correct per participant)	0.62***	---	0.18	0.39**	0.19	0.07	-0.02	-0.43**	-0.34*
3. Word recognition	0.24	0.35**	---	-0.23	0.30*	0.14	0.01	-0.17	-0.21
4. Spatial working memory	0.43***	0.61***	0.45***	---	0.01	-0.03	-0.18	-0.41**	-0.52***
5. Age (in months)	0.00	0.12	0.32*	0.06	---	-0.25	0.00	0.09	0.35**
6. Factor Print reading	-0.05	0.13	0.29*	0.04	-0.09	---	-0.03	-0.08	-0.11
7. Factor Digital fiction reading	-0.11	0.00	0.06	0.10	0.13	0.17	---	0.39**	0.16
8. Factor Digital mixed genre reading	0.08	0.12	-0.06	0.04	0.11	0.32*	0.16	---	0.35**

9. Factor Leisure activities on smartphones	-0.30*	-0.19	-0.03	0.23	0.34*	-0.04	0.32*	0.16	---

*$p < 0.025$, **$p < 0.005$, ***$p < 0.0005$

Note. The lower triangle features correlations in the print medium, the top triangle correlations in the digital medium. P-values were corrected for multiple comparisons, and thresholds adjusted. Correlations with factor scores were calculated for a subsample with available reading habits and device use data: print condition ($N = 55/66$), digital condition ($N = 55/62$).

Greater accuracy (fewer errors) in recalling the location of information was positively associated with comprehension and spatial working memory in both media, but the association with spatial working memory was only significant in the print medium. Word recognition was not significantly correlated with location recall in either the print medium or the digital medium. Spatial working memory exhibited a stronger correlation with location recall for print compared to digital. These differences indicate that different participant characteristics influenced the ability to recall the location of information.

Table 6

Result of Ordinal Generalized Linear Mixed Model on Effect of Medium, Text Structure, Reading Comprehension and Spatial Working Memory on the Recall of the Location of Information

	Location of Information Error Score			
Predictors	*Odds Ratios*	*SE*	*CI*	*p*
Medium [digital]	0.53	0.12	0.34 – 0.81	**0.004**
Text structure [hierarchical]	0.67	0.26	0.31 – 1.43	0.302
Comprehension [correct]	1.38	0.31	0.89 – 2.13	0.154
Spatial working memory (z-transformed)	1.28	0.12	1.06 – 1.53	**0.009**
Word recognition (z-transformed)	1.06	0.09	0.91 – 1.25	0.437
Age (z-transformed)	1.01	0.09	0.85 – 1.19	0.948
Item in text (z-transformed)	1.17	0.23	0.79 – 1.71	0.433
Presentation order [as second text]	1.04	0.11	0.85 – 1.28	0.^ 695
Testing location [school]	0.61	0.13	0.40 – 0.94	**0.024**
Gender [male]	0.95	0.16	0.67 – 1.33	0.749
7|6	0.00	0.00		
6|5	0.01	0.00		
5|4	0.01	0.00		

4|3	0.03	0.01
3|2	0.09	0.03
2|1	0.21	0.08
1|0	0.75	0.27

Random Effects

σ^2	3.29
$\tau_{00\ subject}$	0.33
$\tau_{00\ itemID}$	0.41
$\tau_{11\ subject.porder.code}$	0.01
$\tau_{11\ subject.comp.factor.code}$	0.00
$\tau_{11\ subject.z.item\_in\_text}$	0.08
$\tau_{11\ subject.texttype.code}$	0.00
$\tau_{11\ itemID.z.SWM}$	0.01
$\tau_{11\ itemID.porder.code}$	0.00
$\tau_{11\ itemID.comp.factor.code}$	0.39
$\tau_{11\ itemID.z.wr}$	0.00
$\tau_{11\ itemID.z.age}$	0.01
$\tau_{11\ itemID.location.code}$	0.15
$\tau_{11\ itemID.gender.code}$	0.06
$\tau_{11\ itemID.cond.code}$	0.33
ρ_{01}	
ρ_{01}	
$N_{subject}$	128
N_{itemID}	12
Observations	1477

Note. The values 7|6, 6|5 etc. are threshold coefficients. They represent the combined effect of all predictors and indicate the points on the underlying continuous scale at which the probability of being in one category versus another changes.

Effects of Medium, Comprehension of the Text, and Spatial Working Memory on Recall of the Location of Information

There was a significant effect of medium ($OR = 0.53$, $SE = 0.12$, $p < 0.01$), indicating a higher probability of accurately recalling the location of information in the print medium (see Figure 1). Importantly, this difference held even when controlling for individual differences in comprehension, spatial working memory, and word recognition, as well as testing location (school vs. lab), gender, and age (see Table 6). In ordinal logistic regression, threshold coefficients provide insights into how changes in predictor variables collectively influence the odds of transitioning between adjacent response categories. For that reason, p-values for the threshold coefficients are of limited interpretability and are not reported.

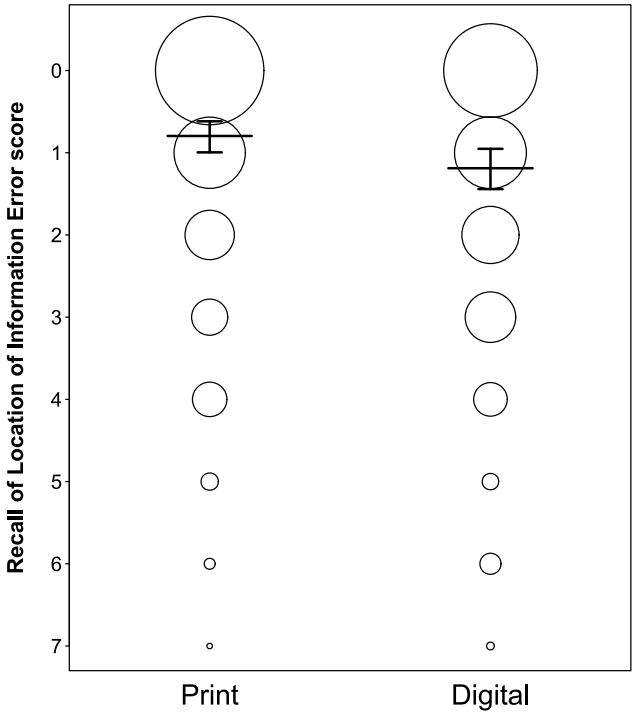
Regarding our second hypothesis, there was no significant support for a relation between the ability to recall the location of information and comprehension of the text ($OR = 1.38$, $SE = 0.31$, $p = 0.153$). To facilitate comparison with existing studies which conceptualised accuracy of information location recall as binary (Lovelace & Southall, 1983; Rawson & Miyake, 2002; Rothkopf, 1971; Zechmeister et al., 1975), we conducted an analysis in which location recall accuracy was dichotomised as correct or incorrect exact location. There was a significant effect of comprehension ($OR = 1.42$, $SE = 0.22$, $p < 0.05$), and higher location recall accuracy was associated with correctly answered comprehension questions.

An additional analysis (not pre-registered) yielded a positive effect of spatial working memory ($OR = 1.28$, $SE = 0.12$, $p < 0.001$). For each increase of one standard deviation in spatial working memory score, the probability of being more accurate at location recall (lower error score) increased by 28%. There was no evidence that age influenced location recall over and above other predictors ($OR = 1.01$, $SE = 0.09$, $p = 0.948$). Of note, participants tested in school

were significantly worse at location recall ($OR = 0.61$, $SE = 0.40$, $p < 0.05$) than those tested in the lab.

Figure 1

Recall of Location of Information Error Score for Print and Digital Medium



Note. A high value indicates greater error in recalling the location of information. The diameter of the circles is proportional to the number of observations. Horizontal lines depict the estimates of the fitted model, vertical lines the confidence limits.

Effect of Text Structure on Recall of Information Location

There was no effect of text structure and, therefore, no support for the prediction that location recall would be inferior for hierarchical texts ($OR = 0.67$, $SE = 0.26$, $p = 0.302$). Presentation order (hierarchical or linear text presented first) had no significant influence on location recall ($OR = 1.04$, $SE = 0.11$, $p = 0.695$), meaning that participants did not improve on

this measure, despite being aware of the task. There was no evidence for any influence of item order (order of appearance in the text) (OR = 1.17, SE = 0.23, p = 0.433).

Relation Between Digital Reading Habits, Device Usage and Ability to Recall the Location of Information

To explore the association between reading habits, device use and recall of location of information we fitted a model with interactions between medium and the factors for digital fiction reading, digital mixed genre reading (non-fiction, blogs, and comics), and leisure activities on smartphones in a subsample of 110 participants where reading habits data were available. This approach was chosen due to it resulting in more stable estimates, as compared to the pre-registered sub-group analysis (Kontopantelis et al., 2018). The model yielded a significant interaction between medium and digital mixed genre reading (OR = 0.67, SE = 0.14, p < 0.05): Participants who engaged in digital mixed genre reading were less likely to accurately recall the location of information in the digital medium. There was no significant interaction between medium and digital fiction reading (OR = 1.37, SE = 0.25, p = 0.085) or leisure activities on smartphones (OR = 1.22, SE = 0.20, p = 0.229).

Discussion

This is the first study to investigate the effects of reading medium (print vs. digital) and text structure (linear vs. hierarchical) on the ability to recall the location of information in expository texts in young readers (9- to 12-year-olds). Participants were worse at recalling the location of information in the digital medium. No difference in location recall was observed between linear (chronological order of events) and hierarchical (featuring relations and causal chains) texts. Location recall was not related to accuracy on the comprehension questions. However, readers with better spatial working memory were better at location recall. In addition,

there was a negative association between frequency of digital mixed genre reading and information location recall in the digital medium.

Accuracy in location recall was high in both media, indicating that, for these texts, young readers engaged with the task and were able to encode and recall the location of information in both print and digital short texts, even though they were not instructed to do so. This is in line with earlier research (Lovelace & Southall, 1983; Rawson & Miyake, 2002) but we note that some adult studies report performance near to chance (Rothkopf, 1971; Therriault & Raney, 2002). The observed discrepancy in results could be attributed to the length of the texts used across studies (12 A4 pages in Therriault and Raney (2002) versus 2 A4 pages in the current study), and the definition of chance level (determined via pilot study in Therriault & Raney, 2002). Interestingly, participants did not improve significantly in information location recall in the second text, even though they would have been aware of the location recall task after responding to the first passage. This suggests that participants retained some level of memory of where information was located without explicitly attempting to memorise it during reading. This finding supports the notion that the encoding of the location of information is incidental when processing text (Inhoff & Weger, 2005; O'Hara et al., 1999; Payne & Reader, 2006; Rothkopf, 1971).

Location recall was poorer for digital than print media. This contrasts with the results for adults (Mangen et al., 2019), where there was no difference between media for reading long, narrative texts. We note that our sample size was sufficient to address the substantial variability in reading and related skills among young readers and to allow for reliable detection of any effect. A critical difference between studies, in addition to age group, is that participants in the digital medium in the current study had to scroll to read the entire text. Mangen et al.'s (2019)

study of adult readers used e-books with hard page boundaries. Thus, a potential explanation for poorer performance in the digital medium is the disruption caused by scrolling (see also Piolat et al., 1997, who found better memory for content and information location for paging compared to scrolling when reading digitally). Future studies should consider these differences when comparing print vs. digital to understand any differences between media. This could help clarify whether performance differences should be attributed to the medium in general or are specifically related to age group, and/or digital reading environment.

Related to this point, we note differences in measurement that may impact on the sensitivity and suitability and measures to detect meaningful relations. First, studies differ in the granularity of assessment methods used to measure the recall of the location of information. In contrast to much previous research that has found a relation between location recall and comprehension, we assessed the degree of accuracy, rather than a binary standard of correct-incorrect. When conceptualised as binary, we found a significant relationship between comprehension and location recall accuracy in line with other research (Lovelace & Southall, 1983; Rawson & Miyake, 2002; Rothkopf, 1971; Zechmeister et al., 1975). Measurement approach might influence sensitivity to detect medium effects. Second, in contrast to our study, much previous research (Lovelace & Southall, 1983; Rawson & Miyake, 2002) has used a cloze task to assess reading comprehension. This may unintentionally provide clues for the location of information because cloze task items involve rewritten sections of text. These differences in assessment underscore the need for further research to explore the relationship between reading comprehension and memory for information location.

Contrary to our hypothesis, there was no difference in location recall between linear and hierarchical texts. This suggests that alignment of text structure with event sequence did not

enhance location encoding and recall. Further, the analysis revealed that performance on the reading comprehension measure did not significantly predict location recall. Our findings align with previous studies on children in the print medium (Cataldo & Oakhill, 2000) and adults across both media (Mangen et al., 2019), where no relation was evident. However, the bulk of evidence (with adults) finds a positive relationship in both print (Lovelace & Southall, 1983; Rothkopf, 1971; Zechmeister et al., 1975) and digital (Rawson & Miyake, 2002). Like Cataldo and Oakhill (2000) but different to other studies, we controlled for word recognition, a critical influence on reading comprehension across age groups (García & Cain, 2014). Our results suggest that reading comprehension did not influence memory for location recall beyond the influence of these predictors.

This study is the first to examine the relation between spatial working memory on the ability to recall the location of information in the print and digital media in young readers. Spatial working memory was positively associated with location recall, irrespective of medium, in line with studies of adult readers in print (Le Bigot et al., 2009) and hypermedia learning environments (Rouet et al., 2012). Our results suggest that the ability to retain spatial information in memory enhances the encoding and recall of information location. It is yet to be determined if this is valid only for spatial information; Rawson and Miyake's (2002) study of adult readers indicates that performance on visuospatial tasks was not predictive of location recall, once verbal abilities were controlled.

Our findings indicate that frequency of digital device use does not enhance location recall for digital texts. However, certain activities were associated with poorer performance; frequency of digital mixed genre reading was negatively related with location recall, suggesting that reading non-fiction, blogs, or comics may not support the encoding of information location. In

contrast, digital fiction reading and leisure activities on smartphones were not related to location recall.

Limitations

In addition to the limitations noted above, we highlight three others. First, participants were tested in either a school or a laboratory setting. In school, up to 10 students were tested simultaneously, whereas in the laboratory, a maximum of 2 students were tested concurrently. We found that participants tested in school had lower accuracy in location recall than those tested in the laboratory, and we cannot rule out that experimenter-participant ratio contributed to differences in participant performance. Second, the choice of digital device for testing could have influenced the outcome. Participants were assessed using a PC, and children interacted with the digital interface using a computer mouse, a device that is not as familiar to them as tablets or smartphones. A third limitation is the association between text structure (linear vs. hierarchical) and topic (history vs. palaeontology). Different disciplines and types of content presentation feature different discourse structures (Meyer & Freedle, 1984; Meyer & Ray, 2011). Despite efforts to ensure comparability in text characteristics such as readability, word complexity, syntactic structure, and referential cohesion, this associations remains a potential confounding factor. Further, we did not explore the role of text length or types of information (e.g., surprising or contradictory information). Lastly, we did not include other known predictors of reading comprehension, such as prior knowledge (Best et al., 2008). Future studies should consider incorporating these factors.

Conclusions

This is the first study investigating the effect of medium on the recall of location of information in readers aged 9 to 12 years. It demonstrates that young readers perform above

chance at recalling the location of information in both print and digital text. Contrary to previous research with adults (Mangen et al., 2019), location recall was poorer when reading in the digital medium. This study advances current understanding of medium effects on location recall for adults reading narrative text (Mangen et al., 2019), by providing evidence for related media differences for expository text and in young readers. The differences between print and digital reading, and the potential disadvantage for digital, indicate a need for future studies on search and retrieval mechanisms in both media to better understand the impact on young readers' learning from digital texts.

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