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# Reading digital text involves working memory updating based on task characteristics and reader behavior

Carolin Hahnel[a,b,*], Frank Goldhammer[a,b], Ulf Kröhne[a], Johannes Naumann[c]

[a] German Institute for International Educational Research (DIPF), Frankfurt am Main, Germany
[b] Centre for International Student Assessment (ZIB), Germany
[c] Goethe University, Frankfurt am Main, Germany

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ABSTRACT

Receiving and using web-based information has become part of everyday life, but the non-linear presentation of information can make considerable demands on cognitive resources, affecting text comprehension. This study examined whether memory updating predicts students' comprehension of digital hypertext over and above skills in reading linearly structured text, and whether this association is affected by particular characteristics of reading tasks, the hypertext and individual reading behavior. Measures included reading comprehension as assessed via hypertext (digital reading) and linear text (linear reading) as well as memory updating among 15-year-old German students ($N$ = 288). The number of nodes in a hypertext and cognitive reading operations required for task processing were regarded as task characteristics. Indicators of reader behavior were derived from log files. The results demonstrated a general effect of memory updating on digital reading over and above linear reading. This effect was not affected by the number of available nodes but by cognitive reading operations and individual reader behavior. Implications for students' cognitive processing of hypertexts are discussed.

## 1. Introduction

In today's society, receiving and using information from the World Wide Web (WWW) has become integral part of many private, academic, and occupational activities (Leu, Kinzer, Coiro, & Cammack, 2004). As a result, measures of reading web-based information have been included in international comparative studies like the Programme for International Student Assessment (PISA), which aims to evaluate the skills and knowledge of students at the end of compulsory education (OECD, 2011). Web-based information is frequently structured in the form of non-linearly organized text pieces ("nodes") that are associated with one another and accessible through hyperlinks. Hypertexts offer readers numerous ways of collecting and combining pieces of information for specific reading purposes. However, processing information that is not presented contiguously can seriously affect comprehension of a text (Coiro, 2011; Rouet, 2006), since individuals' cognitive resources are limited (Feldman Barrett, Tugade, & Engle, 2004) and decision-making and navigation requirements add to the load on readers' working memory (WM; DeStefano & LeFevre, 2007; Foltz, 1996; Scheiter, Gerjets, Vollmann, & Catrambone, 2009).

In the present study, we investigated interindividual differences in 15-year-old German PISA students' comprehension of hypertexts. We examined how such differences are related to memory updating – the individual skill of actively monitoring and manipulating WM content (e.g., Oberauer & Kliegl, 2006). We aimed to investigate (1) whether memory updating is predictive of students' hypertext comprehension over and above their general reading skills, and (2) whether such an association is affected by particular characteristics of reading tasks, the hypertext and reading behavior. Examining these research questions will provide evidence on the relation between hypertext comprehension and WM (e.g., Naumann, Richter, Christmann, & Groeben, 2008; Pazzaglia, Toso, & Cacciamani, 2008), and generate further insights on the nature of information processing from hypertext. In the following, we will refer to the skills of comprehending electronic hypertext and linearly structured text as digital reading and linear reading, respectively.

### 1.1. Working memory and digital reading

Reading is an individual process of receiving and processing written information, ranging from decoding and recognizing words up to higher processes of word-text integration and meaning making (Perfetti & Stafura, 2014). In both digital and linear text, information should be conveyed in a coherent form that enables readers to extract

* Corresponding author at: German Institute for International Educational Research (DIPF), Schlossstraße 29, 60486 Frankfurt am Main, Germany.
*E-mail address:* hahnel@dipf.de (C. Hahnel).

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meaning and to form a mental representation of the text situation (Foltz, 1996; Kintsch, 1998). In this regard, WM generally plays an essential role since individuals need to integrate information retrieved from the text and information activated from their long-term memory (e.g., Daneman & Merikle, 1996; Hannon, 2012; Oakhill, Yuill, & Garnham, 2011). Hypertexts, though, offer readers a great deal of freedom in terms of how they receive information by simultaneously providing fewer cues about what information to process next and where to find it (Foltz, 1996). Therefore, digital reading requires increased activation of cognitive resources to allow readers to deal appropriately with the non-linear text structure without getting lost (Coiro, 2011; Gyselinck, Jamet, & Dubois, 2008; Srivastava & Gray, 2012). Accordingly, visuospatial WM capacity was shown to be associated with the recognition of hypertext structures among sixth graders, whereas verbal recall predicted their semantic knowledge (Pazzaglia et al., 2008). These effects were not due to linear reading skills, prior knowledge or short term memory. Similar effects were found for university students. Readers with a low verbal WM capacity recalled noticeably less information from digital text than from linear text (Lee & Tedder, 2003), and low visuospatial WM capacity was associated with difficulties in recalling hypertext structures and keeping track of link hierarchies (Rouet, Vörös, & Pléh, 2012).

Previous studies have mainly related digital reading processes to verbal and visuospatial WM subcomponents, but not to the domain-general WM functions of active information storage and processing. Conceptualizing WM as "a system for building, maintaining and rapidly updating arbitrary bindings" for goal-directed information processing (Wilhelm, Hildebrandt, & Oberauer, 2013, p. 3), the memory updating paradigm was found to be a good representation of the individual skill to flexibly bind structures into mental WM representations (Schmiedek, Hildebrandt, Lövdén, Wilhelm, & Lindenberger, 2009). In contrast to other WM theories (e.g., Engle, 2002; Miyake et al., 2000), WM capacity limits are assumed to arise from interference due to temporary bindings that limit the complexity of novel representations (Oberauer, 2009). Since digital reading requires making sense of text by simultaneously monitoring and flexibly manipulating representations of the text situation and spatial relations between nodes, it should be closely related to memory updating.

### 1.2. Task influences

In general, readers are sensitive to demands of reading tasks that influence the way of their cognitive information processing (cf. Kendeou, van den Broek, Helder, & Karlsson, 2014; McCrudden & Schraw, 2007; Naumann, 2015; Rouet, 2006). Such demands are often described as sources of cognitive load in WM (DeStefano & LeFevre, 2007; Rouet, 2009; Scheiter et al., 2009). Higher cognitive load is associated with differences in learning performance across different text structures (Zumbach & Mohraz, 2008), navigational maps (Amadieu, van Gog, Paas, Tricot, & Mariné, 2009; Scott & Schwartz, 2007), and reading orders (Madrid, Van Oostendorp, & Puerta Melguizo, 2009). Readers reported less cognitive load, for example, when they had high prior knowledge or positive attitudes towards the text content (Amadieu et al., 2009; Scheiter et al., 2009).

In PISA (OECD, 2013, p.66), "mental strategies, approaches or purposes that readers use to negotiate their way into, around and between texts" are described as "reading aspects". These include the facets *access and retrieve*, *integrate and interpret*, *reflect and evaluate* and – the digital reading-specific aspect – *complex*. Table 1 lists examples of each reading aspect as well as operations required for task processing. Illustrated tasks refer either to a hypertext detailing an email exchange between two girls looking for a sports club ("Sports Club"), or a social media-like language learning platform ("Language Learning"). The different methods of text processing invoked by these reading aspects (Table 1) might involve WM representations being updated differently.

**Table 1**
Examples of reading aspects in the digital reading items.

| Reading aspect | Description | Number of items | Instruction of an example task | Goal process in task example |
|---|---|---|---|---|
| *Access and retrieve* | Finding, extracting and combining one or more pieces of information explicitly stated in the text | 6 | Unit *Sports Club*: which sports club offers the cheapest monthly rates for 15-year-olds? | Searching four websites to identify a match with a single specified criterion |
| *Integrate and interpret* | Inferring on the basis of implicit assumptions, relations, or implications within the text to show a holistic understanding of the text | 7 | Unit *Language Learning*: what kind of service does language-learning.com provide for learners? | Making inferences from text information on the function of a website |
| *Reflect and evaluate* | Drawing upon one's own knowledge and experiences, and relating them to text content and form | 3 | Unit *Language Learning*: look at "My Messages". Do you think Rafael should take up the VocabTrainer suggestion? Write Yes or No and give a reason for your answer. | Evaluating the credibility and utility of an advertisement through the use of contextual information |
| *Complex* | Providing reading tasks that are as realistic as possible (i.e., encompassing features of all the former aspects) | 3 | Unit *Sports Club*: which sports club would suit Liz and Anna best? Write the name of the sports club and give two reasons for your answer. | (1) Locating descriptions in several websites by following a series of links, (2) comparing a series of descriptions with a set of requirements retrievable from the e-mail exchange, (3) integrating information from several websites and forming an opinion consistent with the requirements stated in the e-mail exchange |

Note. Note that these reading aspects are not intended to be mutually exclusive but emphasize particular ways of text processing. Information about the items is derived from the PISA coding guidelines.