Comprehension of networked hypertexts in students with hearing or language problems

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A R T I C L E   I N F O

Keywords:
Hypertext
Digital reading comprehension
Deaf/hard-of-hearing
Developmental Language Disorder
Vocabulary

A B S T R A C T

The compensatory effects of a graphic overview and the effects of students' cognitive-linguistic skills on the comprehension of networked hypertexts were investigated in students with hearing or language problems. Networked hypertext comprehension of 28 deaf/hard-of-hearing (DHH) students and 33 students with Developmental Language Disorder (DLD) was compared to that of 77 hearing students of a comparable reading level and 60 hearing students of a comparable age. The results showed lower networked hypertext comprehension of DHH students and students with DLD compared to hearing students of the same age, but not to those of the same reading level. Hypertext comprehension was mainly predicted by vocabulary level. Across groups, students with lower vocabulary benefitted from a graphic overview in comprehending networked hypertexts. It was concluded that although DHH students and students with DLD have more problems with comprehension of networked hypertexts than hearing students without language problems, the difficulties are predominantly caused by their generally lower vocabulary size.

1. Introduction

The shift in educational settings from using printed material towards the digitalization of information sources calls for more clarification of how students' digital reading develops. Although the networked structured hypertext is the most frequent available digital text type on the internet, there are studies showing that comprehension of this type of hypertext is generally lower than comprehension of a linear digital text in typically developing readers (Destefano & Lefevre, 2007; Lee & Tedder, 2003). Studies in typically developing students have shown that both textual tools as well as the readers' cognitive-linguistic skills can play a role in the comprehension of networked hypertexts. It has been shown that the use of organizational textual tools such as a graphic overview can visualize the underlying text structure and thus facilitate hypertext comprehension (Destefano & Lefevre, 2007). Also, having higher vocabulary and verbal and visuospatial working memory capacity has been shown to support networked hypertext comprehension (Blom, Segers, Knoors, Hermans & Verhoeven, 2018; Pazzaglia, Toso, & Cacciarmiani, 2008). Studies on digital text comprehension in special populations are scarce, especially in the younger age group (Segers, 2017). Students with hearing or language problems show a delay in their general reading development and generally have a lower vocabulary size, as well as a lower verbal and visuospatial working memory capacity (e.g., Archibald & Gathercole, 2006; Rice & Hoffman, 2015). These students may thus face additional problems in comprehending networked hypertexts, and a graphic overview may be beneficial for them. The goal of the current study was therefore to compare the networked hypertext comprehension of deaf/hard-of-hearing (DHH) students and students with Developmental Language Disorder (DLD) to that of hearing peers without spoken language problems and to investigate the compensatory role of a graphic overview and the effects of cognitive-linguistic skills for these students.

1.1. Networked hypertext comprehension

While online, a reader faces different types of digital texts. Linear digital texts are read from top to bottom, in a linear way. A hypertext, a digital text containing hyperlinks, can be hierarchically structured or networked structured. A hierarchically structured hypertext has an underlying structure that is recognizable for the reader. The reader can logically assume that a page about birds can be reached through the page about animals. In a networked structured hypertext, the type that is most frequent available on the internet, all pages that share some

https://doi.org/10.1016/j.lindif.2019.05.006
Received 17 November 2018; Received in revised form 22 April 2019; Accepted 11 May 2019
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content-related overlap are linked together. As a consequence, there is no clear underlying structure. The general assumption that comprehension of hypertexts is more difficult than comprehension of linear digital texts is not consistently shown in all studies (Blom et al., 2018; Fesel, Segers, & Verhoeven, 2018; Burin, Barreyro, Saux, & Irrazabal, 2015; Destefano & Lefevre, 2007; Zumbach & Mohraz, 2008). This might be due to the different hypertext structures that are used or that there is large variation in cognitive-linguistic skills among the participants across the studies. For example, skilled adult readers may experience less problems, than children with low prior knowledge. When the role of the readers’ skills is considered, it is suggested that comprehension of a networked hypertext mainly depends on the readers’ cognitive-linguistic skills among which vocabulary knowledge and working memory capacity play a prominent role (Blom et al., 2018; Destefano & Lefevre, 2007; Pazzaglia et al., 2008).

Blom et al. (2018) found in their study that, compared to secondary school students with high vocabulary levels, students with lower vocabulary levels seem to have more difficulties with comprehending a networked hypertext than a linear digital text. It is suggested that students with lower vocabulary have more difficulties with making a coherent story of the text content if the text structure is not clear enough to help them making explicit connections between pages. In the same vein, prior knowledge and background knowledge are actively involved in making explicit connections between pages. Other studies have also shown that readers with little prior or background knowledge have more difficulties with comprehending a networked hypertext than a hierarchically structured hypertext. Reading comprehension of readers with high prior knowledge or background knowledge was not affected by text structure (Amadieu, Tricot, & Mariné, 2009; Potelle & Rouet, 2003). The authors of these studies also point towards the important role of general world knowledge, together with vocabulary (Illscher, 2003), for making semantic connections between text pages in networked hypertexts.

Similar to the above described effect of vocabulary level, there is an effect of working memory on the relation between text structure and reading comprehension. The readers’ working memory capacity plays a role during hypertext reading (Destefano & Lefevre, 2007). The use of both verbal and visuospatial working memory ensures that the reader is able to remember and integrate all the relevant information from different pages into a coherent story of the text content, while making decisions on which reading path to follow (Pazzaglia et al., 2008). On the one hand, it is suggested that simultaneously performing all these activities during reading hypertexts causes a higher cognitive load which is detrimental for hypertext comprehension (cognitive load theory; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000). On the other hand, the reader is encouraged to take a flexible stand in his own learning process and to actively use his own knowledge to construct a model of an ill-structured text by learning to understand the underlying connection between different pages, which could facilitate hypertext comprehension (cognitive flexibility theory; Spiro & Jehng, 1990). Hahnel, Goldhammer, Kröhne, and Naumann (2017) found in their study among 15-year-old students that efficient working memory skills positively affected digital text comprehension, even after controlling for linear text comprehension. Lee and Tedder (2003) demonstrated that the capacity of verbal working memory influences the effect of text structure on comprehension. Undergraduate students with low working memory capacity had lower text comprehension scores after reading a hypertext than a linear text, whereas students with high working memory capacity did not show differences in comprehension. A possible explanation is that while reading a networked hypertext, the reader must keep the information in memory for a longer period of time, which is more difficult for readers with low working memory capacity. This can be detrimental for readers with low working memory capacity. Indeed, Destefano and Lefevre (2007) point in their review to the beneficial effects of structured texts for readers with low verbal working memory.

1.2. Effect of overview on digital text comprehension

It has been suggested that the use of organizational tools in a networked hypertext, such as navigation maps or hyperlink preview information, can play a compensatory role in comprehension. This is particularly the case for readers who have difficulties with reading and comprehending these texts as it would support them to follow a more coherent navigation path (Amadieu & Salmeron, 2014; Kester & Kirschner, 2009). A specific type of an organizational tool is a graphic overview. It is a visualization of the underlying text structure in which the connections between pages are presented and can be dynamic (i.e., navigation possible by clicking on the nodes in the overview) or static (i.e., non-clickable words in the overview). There has been a debate about the effect of a graphic overview: On the one hand, the availability of a graphic overview may help the reader to navigate through a networked hypertext and facilitate comprehension, but on the other hand it could distract the reader and thereby decrease comprehension (Salmeron, Canas, Kintsch, & Fajardo, 2005). Study results thus far remain inconclusive; while one study (Brinkerhoff, Klein, & Koroghlanian, 2001) demonstrated that the overview has no added value on hypertext comprehension and navigation, another study (Müller-Kalthoff & Möller, 2004) did show that an overview can lead to higher comprehension scores.

The compensatory effect of an overview on hypertext comprehension partly depends on the readers’ skills (Amadieu & Salmeron, 2014). For example, Fesel et al. (2018b) found that for children with lower prior knowledge, the availability of an overview facilitates hierarchically structured hypertext comprehension. Level of vocabulary and verbal working memory capacity did not affect the effect of an overview on hypertext comprehension. The study of Vörös, Rouet, and Pléh (2009) showed that the effect of an overview depends on the visuospatial working memory capacity of the adult reader. If readers have lower visuospatial working memory capacity, they benefit from the availability of an overview while reading a hypertext. More specifically, when an overview was present readers with lower visuospatial working memory capacity performed comparable to readers with higher visuospatial capacity in describing the structure of the hypertext while the latter group outperformed them when no overview was present. It remained unclear whether this also affected comprehension of the text content. In the same vein, Naumann, Richter, Flender, Christmann, and Grobein (2007) showed in their study among university students that hypertexts with signals, such as navigable overviews or hyperlinks that show the conceptual structure of a text part, are more beneficial for poor readers than for good readers. The authors suggested that the signals can help the poor readers with a coherent representation of the text structure, thereby facilitating text comprehension. No studies have yet investigated whether verbal working memory capacity and vocabulary size are also important in the effect of a graphic overview on networked hypertext comprehension.

1.3. Readers with hearing or language problems

The information above suggests that networked hypertext comprehension can be facilitated by the availability of a graphic overview and the readers’ working memory and vocabulary. Students who are deaf or hard-of-hearing (DHH) or who have a Developmental Language Disorder (DLD) show problems in their spoken language development. Whereas the spoken language delay in DHH students stems from their restricted auditory input, the exact cause in students with DLD is largely unknown. Consequently, both groups of students face difficulties in...
their reading comprehension development (Bishop & Snowling, 2004; Kyle & Cain, 2015; Wauters, Van Bon, & Tellings, 2006) and vocabulary (Coppens, Tellings, Verhoeven, & Schreuder, 2011; Rice & Hoffman, 2015) compared to students without hearing or language problems. Additionally, DHH students show a delay in general world knowledge, which is also suggested by a delay in reading development (Convertino, Borgna, Marschark, & Durkin, 2014). A verbal working memory deficit is a particular characteristic that is found in students with DLD (Archibald & Gathercole, 2006; Montgomery, 2000) and the meta-analysis of Vugs, Cuperus, Hendriks, and Verhoeven (2013) showed that the deficit also extends to visuospatial working memory, although to a lesser extent than the verbal component. Studies on visuospatial working memory capacity in DHH students do not show a consistent pattern. Cleary, Pisoni, and Geers (2001) reported lower scores on visuospatial memory tasks in deaf children with a cochlear implant compared to hearing children, whereas a study of Marschark et al. (2015) in deaf individuals with and without cochlear implants did not show differences in visuospatial ability compared to hearing peers. Regarding the verbal working memory, studies of Pisoni et al. (2008) and Pisoni, Kronenberger, Roman, and Geers (2011) showed that deaf students with cochlear implants score lower than hearing students on the memory tasks with spoken stimuli.

Regarding the digital text comprehension of students with hearing or language problems, not much is known yet. Blom et al. (2017) compared the reading comprehension of hierarchically structured hypertexts versus linear digital texts in DHH students, students with DLD and hearing students without hearing or language problems with the same general, offline reading level. The results showed comparable digital text comprehension scores among the three groups of students; the DHH students and students with DLD did not experience more or less difficulties with comprehending hierarchically structured hypertexts than linear digital texts. In addition, verbal working memory capacity positively predicted hypertext comprehension of structured hypertexts. Harris, Terlektsi, and Kyle (2017) demonstrated the relation between vocabulary level and general reading comprehension to be stronger in DHH students than in their hearing peers and another study of Blom et al. (2018) showed an effect of vocabulary level for networked hypertext comprehension in hearing students. But the effects of vocabulary level and both verbal and visuospatial working memory capacity, as well as the graphic overview on networked hypertext comprehension in DHH students and students with DLD has yet to be investigated. Furthermore, the question remains whether, compared to hearing peers without language problems, DHH students and students with DLD would face additional challenges in reading comprehension when the hypertext is networked structured.

1.4. The present study

The research described above shows that DHH students and students with DLD do not have more problems in comprehending hierarchically structured hypertexts than hearing peers. However, the majority of the digital texts on the internet are networked hypertexts and it is still unknown how DHH students and students with DLD comprehend these networked hypertexts versus linear digital texts compared to hearing students, what the effects of cognitive-linguistic skills (i.e., vocabulary level and verbal and visuospatial working memory capacity) are and whether the availability of a graphic overview can play a compensatory role. DHH students and students with DLD generally have a reading development delay of about three years (Haynes & Naidoo, 1991; Wauters et al., 2006). Therefore, we aimed to compare their digital reading comprehension not only with students of the same age without hearing and language problems, but also with students who were three years younger so that they had a comparable general reading level. For the present study, our research questions were:

1. How does comprehension of networked hypertexts, with and without an overview, differ from linear text comprehension in DHH students and students with DLD compared to hearing students of the same age and hearing students with the same reading level?
2. What is the role of vocabulary and verbal and visuospatial working memory in networked hypertext comprehension in the four groups?

Regarding the first research question, we expected reading comprehension to be lower in DHH students and students with DLD than in hearing students with a comparable age and to be comparable to hearing students with a comparable reading level. Additionally, we expected that the gap between the groups of students with hearing and language problems and the age comparison group would be larger in networked hypertexts than in linear texts, as the role of both vocabulary level and working memory capacity (which are known to be lower in DHH students and students with DLD) seems to be more prominent in networked hypertexts. Furthermore, it was expected that the graphic overview would facilitate networked hypertext comprehension, as it can play a compensatory role.

Regarding the second research question, we expected that the effect of the text structure and overview would differ as a function of vocabulary level, verbal working memory and/or visuospatial working memory capacity. More specifically, we expected that students with lower vocabulary level, lower verbal working memory capacity and/or lower visuospatial working memory capacity would show lower comprehension scores when they read a networked hypertext compared to a linear text and lower scores if a graphic overview was not available. Across groups, we expected these differences to be larger in DHH students and students with DLD than in hearing students. Students with a high vocabulary level or high verbal or visuospatial working memory capacity would not show differences in comprehension between text designs.

2. Method

2.1. Participants

This study took place in the Netherlands and involved a total of 207 students. Due to incomplete data, nine students have been excluded from the data analysis, resulting in a total of 198 students in the dataset. The group included 95 boys and 103 girls (AgeMean = 14;0) participated in this study of which 12 students were excluded from the data analysis, resulting in a total of 198 students in the dataset. The second group consisted of students who have a Developmental Language Disorder. In the Netherlands, such a diagnosis is given by diagnostic centers specialized in language and communication disorders when a hearing loss is present. A group of 28 DHH students (AgeMean = 13;2) participated in this study of whom seven were from mainstream schools (grade 5–7; AgeMean = 12–14), one followed education in a special unit in a mainstream school (grade 7; Age = 14) and 20 students were from four different special schools (grade 6–9; AgeMean = 12–15). Except for two students, all DHH students had hearing devices. This was either one cochlear implant (n = 6), two cochlear implants (n = 8), two hearing aids (n = 11) or a combination of both (n = 1). Most of these students used spoken language at home (n = 19), but 5 students used sign language. The remaining students (n = 4) used sign supported speech at home. The second group consisted of students who have a Developmental Language Disorder. In the Netherlands, such a diagnosis is given by diagnostic centers specialized in language and communication disorders when a severe impairment is found on speech or language development. A group of 33 students with DLD (AgeMean = 14;0) participated in this study of which 12 students were
from one special secondary school (grade 7–9; Age\textsubscript{range} = 13–15). While three students followed mainstream education (grade 6 & 7; Age\textsubscript{range} = 12–14), 18 students followed secondary education in a special unit in a mainstream school (grade 7 & 8; Age\textsubscript{range} = 12–15). Special schools for DHH students and students with DLD were approached for participation and letters were distributed for DHH students and students with DLD in mainstream education in which they could sign up for participation.

In addition, it was aimed to find two comparison groups in this study; one group of hearing students with a comparable age and one group of hearing students with a comparable reading level. For the latter comparison group, students who were three years younger participated and it was checked in the analyses whether reading level was indeed comparable via the reading scores on the linear texts. The age comparison group consisted of 77 students without hearing or language problems (Age\textsubscript{Mean} = 13;0) from three different educational level schools at grade 7 (Age\textsubscript{range} = 12–14). The reading level comparison group consisted of 60 students without language or hearing problems from grade 5 and 6 (Age\textsubscript{Mean} = 9–13) of four primary schools (Age\textsubscript{Range} = 10;7). The four groups in this study did not differ from each other in prior knowledge about the text content they were going to read, F(3,186) = 1.86, p = .14. Parental consent was obtained and the project was approved by the ethical committee from our research institution and in line with the Code of Ethics for Research in the Social and Behavioural Sciences involving Human Participants in the Netherlands.

2.2. Design

A $4 \times 2 \times 2$ mixed design with four groups (DHH, DLD, age comparison, reading level comparison), two text structures (linear text, networked hypertext) and two types of overview (with, without) was constructed. To investigate the effect of the cognitive-linguistic skills, interactions of all three factors with vocabulary, verbal working memory and visuospatial working memory were investigated as well. The students read all four text designs (linear text with an overview, linear text without an overview, hypertext with an overview and hypertext without an overview) once with four different text topics, resulting in four measurements per student. The four text contents are from a previous study (Klois, Segers, & Verhoeven, 2013) that has shown that these four differed in difficulty with regard to comprehension level. Therefore, a randomized block design was used to assign the reading order and text topic randomly participants.

2.3. Materials

Four texts from Klois et al. (2013) were adapted and changed into a linear digital text as well as into a networked hypertext, both with and without a graphic overview (see Fig. 1). The expository texts were about the flora and fauna history of Oceania (669 words), Russia (649 words), South America (681) and Southeast Africa (702 words) and contained ten pages. Although the exact content remained the same in the four text designs, the features differed. In the linear text, the student started at the first page and could only click on ‘back’ or ‘further’ to navigate to the previous or next page. The networked hypertext structure was based on the hierarchical structure of the Blom et al. (2017) study, in which the hypertext was built with a main page, three first-level pages and six second-level pages. In the current design, six nonhierarchical links across the three levels were added in the text, resulting in networked hypertexts with a total of 15 hyperlinks within the text and 15 links in the sidebar next to the text; on each page, there was a sidebar next to the text with a link that directed the reader to the main page and in case of a second-level page also a link to the first-level page above the current page. The students could navigate through the hypertext by clicking on the blue hyperlinks on each page or by clicking on the ‘main page’ button. The hyperlinks were words on a text page that showed some overlapping information with another page and were therefore linked to that page. For one linear text and one hypertext, a graphic overview was constructed that visualized the underlying text structure and connections between pages. This overview was present above each page throughout the text. All four text designs were displayed on a laptop.

2.4. Measures

2.4.1. Digital text comprehension

Students’ digital text comprehension was operationalized into textbase knowledge and deeper structure knowledge.

Five explicit and five implicit four option multiple-choice questions were constructed for each text, adapted from the questions from Klois et al. (2013). Answers on the explicit questions could be found explicitly in the text content, while the students had to make inferences to answer the implicit questions. The sum score on the correct answers for both the explicit and implicit questions determined students’ score on textbase knowledge. Reliability analysis showed a good reliability (alpha = 0.87 in present study). Additionally, twelve multiple-choice questions other than the comprehension questions were constructed to measure the students’ level of prior knowledge of each text content.

Concept maps were used to measure deeper structural knowledge of the text content, as it represents the students’ situation model and thus the person’s conceptual understanding of the text (Cañas et al., 2005; Kintsch & Van Dijk, 1978). Students received a paper in which the topic of the text was already written in the center and they were instructed to complete the concept map with all the concepts they could remember from the text. To calculate the complexity of the concept map, the scoring system from Klois et al. (2013, based on Evreklı, İnel, & Balım, 2010) was used. They showed a high inter-reliability scores between two raters and no disagreement on scoring the first ($k = 0.95$) and second-level ($k = 0.84$) concepts of the concept maps. Complexity of the concept map was calculated by counting all the first level (directly linked to the central theme), second level (linked to first level) and third (or above) level (linked to second level) concepts and giving them respectively 2, 4 and 6 points each. The total sum score indicated the complexity of the concept map which represented the deeper structural text knowledge.

2.4.2. Cognitive-linguistic measures

Students’ vocabulary level was measured by the Dutch version of the Peabody Picture Vocabulary Test-III (Dunn, Dunn, & Schlichting, 2005). Students were presented a booklet with pictures, four on each page. With every page, the researcher named a word and the students had to point to the corresponding picture. Each set consisted of 12 words and all students started at set 8 and stopped when nine or more words within one set were incorrect. The number of correct answers was the students’ raw score. Two DHH students were unable to hear or speechread the words, but it was not possible to adapt the task so that we could use signs without giving away the meaning of the word. Therefore, no vocabulary level scores of these students were available.

Students’ verbal working memory capacity was determined by the total score on the digit span task forward and backward (Kort et al., 2005). In the forward task, the researcher called a sequence of digits and the students had to repeat the sequence in the same order and in the backward task it should be repeated in the reversed order. Both tasks started with a block of two sequences of two digits, which expands with every block. The tasks stopped when the student recalled both sequences in one block incorrectly. The total score is the number of
Fig. 1. Screenshot of (a) a second-level networked hypertext page with graphic overview and (b) a linear text page without a graphic overview about nature (“natuur”).
correct recalled sequences. An adapted version of the digit span task was used, when the student was unable to hear the verbal information. In this version, the researcher fingerspelled a sequence of letters instead of calling digits. This adaptation follows from the literature that there is a high phonological similarity when manually representing the numbers (Hall & Bavelier, 2010). Therefore, letters that have no phonological similarity in Dutch were used in this adapted task (B, F, K, L, M, R, S). Then, the same procedure was followed as the regular forward and backward digit span task. When the student was able to receive both spoken as well as signed information, both tasks were performed. This was the case for 16 DHH students for these students, score on verbal working memory was based on the mean score of both tasks.

Students’ visuospatial working memory was measured with the Corsi Block task (Kessels, Van Zandvoort, Postma, Kappelle, & De Haan, 2000), in which a plateau with nine blocks was presented to the students. The researcher tapped a sequence of blocks, starting with two blocks, and the students had to repeat it in the same order. Each block consisted of two sequences of the same length which increased per block. The task stopped when the students recalled both sequences in one block incorrectly. The total score is the number of correct repeated sequences.

2.5. Procedure

Data collection took place in four sessions. To ensure familiarity with drawing concept maps, all students received a 45-minute lesson in concept mapping. After the lesson, the students filled in the prior knowledge questionnaire. Then, two reading sessions (approximately 20–30 min each) took place in which students read the digital texts from a laptop. When all students in class participated, the lesson was given as classroom instruction and the reading sessions took place in groups of four or five students. They first had to read a practice text of three pages in which the first page contained all practical information with a hyperlink to the second page, the second page containing a ‘forward’ and ‘backward’ button and an example of a graphic overview. Before they started to read the first digital text, students were instructed that they were going to read a text, that they had to answer the questions on paper while reading and that they would draw a concept map on paper about the text content afterwards. When they were finished, the students clicked on the ‘finish’ button and drew a concept map without the text. Then, the same procedure applied for the second text about a different topic, which design was always the opposite of the first. For example, when a student read a hypertext with an overview about a different topic, which design was always the opposite of the students’ reading level as the DHH students and students with DLD did not differ from the students’ complex reading comprehension as measured with the comprehension measures per group and text design. Table 1 shows the mean raw scores and standard deviations on the four text topics differed in level of difficulty, as was shown in previous studies (Blom et al., 2017; 2018; Klois et al., 2013). The afex() function (Singmann, 2013) was used to obtain the p-values of the fixed effects with the Kenward-Roger adjustment, as it yields less biased estimates for small groups (McNeish & Stapleton, 2016). Unstandardized regression coefficients and confidence intervals are reported, as these give an indication of the precision and magnitude of the effect size estimation (Pek & Flora, 2018). Significant effects were further explored with either post hoc tests using the emmeans() package (Lenth, 2018) with Tukey adjustments for unequal sample sizes by default or with follow-up models per group or texttype. Since this was not the focus of this study, significant differences between the two comparison groups (i.e., hearing students) were not reported.

To answer the first research question, two separate models were built with Questions (textbase knowledge) and Concept map complexity (deeper structural knowledge) as outcome variables. Both models started with a maximal omnibus model including all predictor variables (i.e., Group, Texttype, and Overview) and their interactions as fixed effects in the model. To answer the second research question, the same models as above were used, but the interactions with the cognitive-linguistic skills were added (i.e., Vocabulary, Verbal Working Memory and Visuospatial Working Memory) as fixed effects in the omnibus model. The model formulas used in R were respectively:

1. Questions ~ (Group * Texttype * Overview) + Texttopic + (1 | id)
2. Log(ComplexityCM) ~ (Group * Texttype * Overview) + Texttopic + (1 | id)
3. Questions ~ (Group * Texttype * Overview) + Voc + (Group * Texttype * Overview) + VeWM + (Group * Texttype * Overview) + ViWM + Texttopic + (1 | id)
4. Log(ComplexityCM) ~ (Group * Texttype * Overview) + Voc + (Group * Texttype * Overview) + VeWM + (Group * Texttype * Overview) + ViWM + Texttopic + (1 | id).

3. Results

3.1. Descriptive statistics

Prior to the analyses, it was checked whether the aimed reading level comparison group had the same basic reading level by comparing the reading comprehension scores on the linear digital text. Indeed, the groups had similar linear digital text comprehension as measured with the questions, F(2, 118) = 1.23, p = .30, η² = 0.02. Regarding the complexity score of the concept map, there was a main effect of Group, F(2, 117) = 4.43, p = .01, η² = 0.07, but post hoc showed that the DHH students and students with DLD did not differ from the students with a comparable reading level in reading comprehension scores (all p's > .23). Thus, the reading level comparison students had a comparable basic reading level as the DHH students and students with DLD. Table 1 shows the mean raw scores and standard deviations on the comprehension measures per group and text design.

To explore the variance in vocabulary level, verbal and visuospatial working memory between the four groups of students, density plots (see Fig. 2) were drawn. The plots show that there is large variation between the four groups regarding their individual skills. Moreover, it is shown...
that in the group of DHH students and students with DLD, there are also students who performed comparable to the average students within the hearing age comparison group. In addition, correlations between the cognitive-linguistic skills for each group separately show that the relations between these skills differ for each group (see Table 2).

3.2. Comprehension of networked hypertexts versus linear texts

3.2.1. Questions

The results of the linear mixed effects analysis showed that there was a main effect of Texttype, \( F(1, 575.05) = 9.66, p = .002, 95\% CI [0.06, 0.27] \), a main effect of Group, \( F(3, 194.42) = 24.91, p < .0001, 95\% CI [1.04, 1.72] \), and an interaction effect of Texttype and Group, \( F(3, 575.05) = 3.01, p = .03, 95\% CI [−0.35, −0.5] \). Follow up models and post hoc tests revealed that for both the linear text and the networked hypertext, the age comparison students score higher than the DHH students (\( b = 1.16 \) (0.39), \( p = .01 \) and \( b = 1.48 \) (0.37), \( p = .0005 \)) and the students with DLD (\( b = 1.82 \) (0.36), \( p < .0001 \) and \( b = 2.59 \) (0.35), \( p > .0001 \)). The interaction can thus be ascribed to the fact that there are larger differences between the groups in the networked hypertexts than the linear texts (as can be seen in Table 1).

There was no difference in linear text comprehension and networked hypertext comprehension of the DHH students and students with DLD compared to the reading level comparison students (all \( p \) values > .18). There was no significant main effect of Overview, nor were the other interactions significant.

3.2.2. Concept map complexity

There was only a main effect of Group, \( F(3, 194.26) = 27.63, p < .0001, 95\% CI [0.18, 0.31] \). Post hoc test showed that only students with DLD had lower concept map complexity scores compared to hearing age comparison students (\( b = 0.49 \) (0.06), \( p < .0001 \)), while DHH students scored comparable to the hearing same-aged peers (\( b = 0.14 \) (0.07), \( p = .12 \)). DHH students scored higher on text comprehension compared to the reading level comparison students (\( b = −0.21 \) (0.07), \( p = .01 \)), while the students with DLD had comparable comprehension scores (\( b = 0.14 \) (0.06), \( p = .14 \)). There was no main effect of Texttype and Overview, nor where any of the interactions significant.

3.3. Effect of cognitive-linguistic factors on networked hypertext comprehension

3.3.1. Questions

There was a main effect of Texttype, \( F(1, 533.14) = 4.87, p = .03, 95\% CI [0.03, 0.35] \), Vocabulary, \( F(1, 182.68) = 76.87, p < .0001, 95\% CI [0.06, 0.09] \), and Verbal Working Memory, \( F(1, 182.77) = 9.58, p = .002, 95\% CI [0.05, 0.21] \). Overall, students with higher levels of vocabulary, \( b = 0.08 \) (0.01), and verbal working memory, \( b = 0.13 \) (0.04), scored higher on the questions. Furthermore, a significant three-way interaction existed between Texttype, Overview and Vocabulary, \( F(1, 543.41) = 5.69, p = .02, 95\% CI [0.003, 0.022] \). This interaction is visualized in Fig. 3a and b. These suggest that in the texts without an overview, student with lower vocabulary levels have relatively more problems with hypertexts, while this is not the case in texts with an overview. Indeed, in follow up models per text design students with low vocabulary levels, when reading a text without an overview, tended to perform lower on the questions after reading a hypertext than after reading a linear text (\( p < .004 \)), while students with high vocabulary levels did not show a difference in performance between the two text types (\( p = .14 \)). For texts with an overview, this interaction was not significant (\( p = .11 \)).

The above mentioned three-way interaction seemed to be qualified by a four-way interaction between Group, Texttype, Overview and Vocabulary, \( F(3, 539.96) = 2.94, p = .03, 95\% CI [−0.030, −0.003] \). However, after analyzing all four-way interactions one by one (to decrease the chance of a Type I error), the four-way interaction between Group, Texttype, Overview and Vocabulary was only marginally significant (\( p = .05 \)) and hence we interpreted only the three-way interaction. No other main or interaction effects were significant.

3.3.2. Concept map complexity

There was a main effect of Vocabulary, \( F(1, 181.45) = 16.50, p < .001, 95\% CI [0.00, 0.01] \), and Verbal Working Memory, \( F(1, 181.53) = 6.55, p = .01, 95\% CI [0.01, 0.05] \). Furthermore, a two-way interaction of Group with Verbal Working Memory, \( F(3, 180.94) = 2.93, p = .04, 95\% CI [−0.078, −0.002] \) was significant. Students with higher levels of vocabulary drew more complex concept maps than students with lower levels of vocabulary (\( b = 0.08 \)). Follow-up models per group and a visualization of the interaction revealed that there was only a significant positive effect of verbal working memory on concept map complexity score in the reading level comparison students (\( b = 0.03, p = .02 \)) and the students with DLD (\( b = 0.07, p = .02 \)), but not in the age comparison students and the DHH students (\( p's > .17 \)). No other main effects or interactions were significant.

4. Discussion

This study was the first to study the networked hypertext comprehension of DHH students and students with DLD and to examine the effects of the readers’ cognitive-linguistic skills and whether the availability of a graphic overview plays a compensatory role.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Comparable reading level (n = 60)</th>
<th>Comparable age (n = 77)</th>
<th>DHH (n = 28)</th>
<th>DLD (n = 33)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>Questions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear text with overview</td>
<td>5.70</td>
<td>2.30</td>
<td>1−10</td>
<td>7.53</td>
</tr>
<tr>
<td>Linear text without overview</td>
<td>6.13</td>
<td>2.22</td>
<td>1−10</td>
<td>7.82</td>
</tr>
<tr>
<td>Hypertext with overview</td>
<td>5.60</td>
<td>2.11</td>
<td>1−9</td>
<td>7.66</td>
</tr>
<tr>
<td>Hypertext without overview</td>
<td>5.40</td>
<td>2.50</td>
<td>1−10</td>
<td>7.83</td>
</tr>
<tr>
<td>Concept map complexity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear text with overview</td>
<td>29.50</td>
<td>28.45</td>
<td>4−132</td>
<td>50.55</td>
</tr>
<tr>
<td>Linear text without overview</td>
<td>27.56</td>
<td>24.20</td>
<td>0−102</td>
<td>50.57</td>
</tr>
<tr>
<td>Hypertext with overview</td>
<td>25.36</td>
<td>19.94</td>
<td>0−86</td>
<td>49.66</td>
</tr>
<tr>
<td>Hypertext without overview</td>
<td>23.00</td>
<td>25.19</td>
<td>0−146</td>
<td>45.79</td>
</tr>
</tbody>
</table>

Note. DHH = deaf/hard-of-hearing; DLD = Developmental Language Disorder. Density plots for both comprehension questions and concept map complexity can be found in the appendix.
Fig. 2. Density plots showing the variance in the cognitive-linguistic skills (a) vocabulary, (b) verbal working memory, and (c) visuospatial working memory in the reading level comparison students, age comparison students, DHH students and students with DLD.
The first research question focused on the comprehension differences (i.e., textbase comprehension and deeper structural knowledge) between networked hypertexts, with and without an overview, and linear digital texts in students with hearing problems and students with language problems compared to hearing students of a comparable reading level and hearing students of a comparable age. The results confirmed our expectations that, compared to hearing age comparison students, DHH students and students with DLD were disadvantaged on both textbase comprehension and deeper structural knowledge of both the linear texts and the networked hypertexts. When looking at the textbase comprehension, the gap seems to be even larger after reading the networked hypertext than the linear digital text. This result confirmed partly our expectation that, as with general text comprehension (Bishop & Snowling, 2004; Wauters et al., 2006), these two groups of students indeed lag behind the students of the same age without hearing or language problems on digital text comprehension and show additional difficulties regarding the textbase comprehension of networked hypertexts.

Furthermore, results showed that textbase comprehension of networked hypertexts of DHH students and students with DLD was comparable to that of the hearing students with a comparable reading level. Looking at the deeper structural knowledge, the students with DLD also performed comparable to the hearing students with a comparable reading level. This is partly in line with the results of the Blom et al. (2017) study with hearing students that did not show group differences in textbase comprehension and deeper structural knowledge of linear texts and hierarchically structured hypertexts either. Surprisingly, DHH students had less problems with gaining deeper structural knowledge of digital texts than expected. They scored higher than the reading level comparison students. A possible explanation can be found in the suggestion that DHH students appear to have another way of processing information than hearing peers. Marschark, DeBeni, Polazzo, and Cornoldi (1993) found in their study that after reading a passage, DHH students recalled less words than their hearing age comparison peers, but more than their younger reading level comparison peers. Whereas both groups of hearing students were able to recall more relations than words, the DHH students showed the reversed pattern. Marschark and Wauters (2011) suggest that DHH students are less likely to effectively use the relational information for memory tasks. In the current study, the DHH students might have been able to recall as many words related to the texts read, but were not able to draw the relations between them, resulting in less complex concept maps compared to their hearing age comparison peers, but still more complex than the hearing reading level comparison students. In contrast to what was expected, the availability of an overview did not have an effect on the comprehension of the networked hypertexts. This is in line with the study of Brinkerhoff et al. (2001), but the results regarding the second research question seem to suggest that the effect of an overview is depending on the readers’ cognitive-linguistic skills.

The main finding regarding the second research question is that there was an interaction effect of the graphic overview with vocabulary level, but not with verbal or visuospatial working memory capacity on networked hypertext comprehension. When a student with low
vocabulary level reads a text without a graphic overview, the textbase comprehension of a networked hypertext is lower than of a linear digital text. This effect was not visible in students with higher vocabulary level, nor was it present in texts with a graphic overview. This is a replication of a study of Blom et al. (2018) in hearing students only, that also found lower comprehension scores of networked hypertexts only in students with lower vocabulary levels and shows that text structure is of influence on digital text comprehension also in DHH students and students with DLD. The fact that we did not find comprehension differences between the linear digital text and networked hypertext with an overview, seems to suggest that students with lower vocabulary knowledge do need the overview as a guide to better comprehend networked hypertexts while reading the text. The overview can help them to connect the pages with each other and to build a logical and comprehensible representation of the text structure and content, thereby facilitating hypertext comprehension. This is in accordance with studies that show an additional value of organizational tools in readers with little knowledge about the text content and structure (Amadieu & Salmerón, 2014; Fesel et al., 2018). Interestingly, there was only an effect of a graphic overview on the score on the questions that were answered during reading, but not on the score on the concept map complexity which was drawn after reading.

With further regard to the cognitive-linguistic skills, the group differences were ameliorated after vocabulary and verbal working memory were taken into account. These findings suggest that DHH students and students with DLD do not necessarily perform lower than their hearing peers without language problems, but that variation in vocabulary size mainly determine the extent to which DHH students and students with DLD comprehend networked hypertexts. Although the developmental process of these individual skills is associated with the hearing or language problems, the great variety in skills that was shown in the density plots revealed that even in DHH students and students with DLD there are students who perform relatively well and score comparable to hearing students without language problems.

Furthermore, there was a positive relation between vocabulary level and digital text comprehension in general, indicating higher comprehension in students with higher vocabulary. This relation is also reported in studies on general text comprehension (Perfetti & Stafura, 2014) as well as digital text comprehension (Blom et al., 2018; Fesel et al., 2018) and points towards the important role of vocabulary also in the digital age. Contrary to our expectations, no effect of visuospatial working memory in digital text comprehension was found. Pazzaglia et al. (2008) mentioned that during reading digital texts, the verbal memory is involved in retrieving meaning from the text content, whereas the visuospatial aspect is more related to following a coherent reading path and to recognize the underlying structure. As the text comprehension measures used in the present study have focused on meaning retrieval and did not capture comprehension of text structure, this might have affected the effect of visuospatial working memory in this study. Furthermore, a positive relation was found between verbal working memory capacity and deeper structural knowledge of digital texts, but only in reading level comparison students and students with DLD. It is difficult to explain this finding, but visualization of the interaction between group and verbal working memory capacity shows that the positive relation is seen in all four groups and seems to suggest that the small sample size might have accounted for the nonsignificance in the other two groups.

Some limitations should be mentioned. It is important to realize that the groups in this study differed in sample size and even though Tukey and Kenward-Roger adjustments are used, the data should be interpreted with some caution. Further studies should further explore the larger gap in linear versus networked hypertext comprehension between the students with hearing or language problems and age comparison students. To prevent floor-effects in the students with hearing and language problems, we have measured textbase knowledge by letting the students answer the questions while reading the text, whereas deeper structural knowledge was administered with the concept map that they drew after reading the text. For a more complete picture of the effect of an overview on both textbase and deeper structural comprehension of networked hypertexts, future study designs should incorporate textbase questions answered after text reading. Furthermore, the majority of the students with hearing or language problems in this study were from special education. Therefore, the groups are too small to draw conclusions about the effects of education settings. Further research should incorporate larger samples of mainstream students. Finally, the designed hypertext contained a high number of hyperlinks. As Destefano and Lefevre (2007) stated that reducing the number of hyperlinks would lead to better comprehension outcomes, it would be informative to investigate the maximum number of hyperlinks a student can cope with during reading a networked hypertext in future studies. Furthermore, as the present study is one of the first to examine the use of a graphic overview in school-aged students, future studies could take a developmental perspective and focus on the exact age from which students are able to make effective use of the graphic overview.

The results of the current study have theoretical and practical implications. The findings suggest that the performance gap in offline reading is even larger in networked hypertext comprehension. Furthermore, the finding that both text structure and verbal working memory are of influence in digital text comprehension is in line with the cognitive load theory that complex text structures puts a higher demand on the readers’ cognitive load, thereby decreasing text comprehension (Niederhauser et al., 2000). In that respect, our study contributes to the cognitive load theory by showing that this theory also applies to students with hearing or language problems. A practical implication of this study is that practitioners in educational settings should keep in mind that students with hearing or language problems will not necessarily have problems with comprehending digital texts. When they do face problems, facilitation during reading these texts by providing a logical structure in the text or making use of an organizational tool, such as a graphic overview, could lead to a better understanding of the text and more insight into the underlying overlap between pages. Additionally, monitoring of the vocabulary development for DHH students and students with DLD is advised in order to identify potential poor readers on time. When vocabulary development is falling behind, practitioners should invest time in instructional activities that stimulate their vocabulary and reading development.

To conclude, other empirical studies have revealed DHH students and students with DLD to perform below hearing peers on tasks involving vocabulary and working memory capacity. This study is the first, however, to demonstrate the importance of those abilities to digital reading comprehension.

Acknowledgments

We thank Prof. Marc Marschark for his constructive and helpful comments on this study. This work was financially supported by the Royal Dutch Kentalis, Sint-Michielsgestel.
Appendix

Fig. 4. Density plots showing the variance in the scores on the comprehension questions after reading a (a) linear text, (b) linear text with overview, (c) networked hypertext, and (d) networked hypertext with overview in the reading level comparison students, age comparison students, DHH students and students with DLD.
Fig. 5. Density plots showing the variance in the scores on the mindmap complexity after reading a (a) linear text, (b) linear text with overview, (c) networked hypertext, and (d) networked hypertext with overview in the reading level comparison students, age comparison students, DHH students and students with DLD.


