



Working Memory Capacity but Not Prior Knowledge Impact on Readers' Attention and Text Comprehension

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Reading digital texts is a common practice in today's education. Prior studies showed that the coherence of a text can influence text comprehensibility with low degrees of coherence causing attention failures (mind wandering) and, consequently, negatively impacts reading comprehension. In addition, working memory capacity (WMC) and prior knowledge of the subject have been suggested to be related to both reading comprehension and mind wandering. However, results remain controversial as the interaction of these three factors has not yet been explored. Ninety participants either studying law or a different subject read either a coherent or incoherent version of the same unfamiliar hypertext about the copyright law. While reading, they reported self-caught mind wandering with task-embedded thought probes. After reading the hypertext, participants were tested on their text comprehension. Supporting prior findings, mind wandering did occur more frequently when participants read difficult rather than easy texts regardless of their undergraduate course. Moreover, this was modulated by WMC in that participants with lower WMC exhibited more frequent mind wandering than high WMC participants solely when reading low coherent texts. In addition, high WMC participants outperformed low WMC participants on all measures of text comprehension. With a low WMC it seems difficult to inhibit irrelevant information and access related information from working memory, especially when text complexity is high. Interestingly, the present results also indicate that prior knowledge benefits later text comprehension despite not affecting reader's attention. These findings provide insights into processing attention during reading online texts.

Keywords: mind wandering, text difficulty, working memory, reading comprehension, attention, cohesion

INTRODUCTION

In today's education, reading digital texts is a common practice and hypertexts replace traditional linear printed texts in many learning contexts. Moreover, reading is one of the most fundamental tasks while engaging the web. However, Wastlund et al. (2005) showed inferior performance when reading from screen compared to when reading a paper presentation of the same text. They argued that participants experienced higher cognitive workload when reading from screen and this higher cognitive load requires more cognitive resources and is, therefore, physically and mentally more exhausting than reading on paper. Furthermore, in his comprehensive review of the available

literature Dillon (1992) concluded, that reading speeds for hypertexts are reduced compared to print media and comprehension accuracy is lower, especially for cognitively demanding reading tasks (Dillon, 1992). It seems that reading hypertext places different demands on the cognitive system and might, therefore, affect text comprehension in a different manner.

An important factor for text comprehension is the text difficulty. Most research on reading comprehension has focussed on processes of constructing a mental representation of a text. A recent study varied text difficulty by simplifying syntactic structures of sentences and substituting low-frequency words with high-frequency words (Feng et al., 2013, p. 588) in four out of eight passages (each passage ~250 words long) from the Nelson Denny Reading comprehension test (Brown et al., 1981). Participants had to read either an easy or difficult version of the same passages. After reading each of the passages, they answered comprehension questions exhibiting poorer performance in the difficult rather than the easy condition. Feng et al. (2013) argued that reading difficult texts makes it more demanding to construct a situation model of the text. Therefore, in the present study, we directly operationalize text difficulty as the difficulty constructing a situation model from the text. Contemporary theories of text comprehension acknowledge multiple levels of text representations (Kintsch and Van Dijk, 1978; Graesser and McNamara, 2011). According to the model proposed by Kintsch and Van Dijk (1978), there are three levels of representation during reading. The first level is the surface representation, consisting of the texts literal wording. In this level, readers do not necessarily understand the meaning of a text and have to syntactically process the information first. The second level is the textbase level, in which the meaning of the text is represented as a network of concepts and propositions of the text. In this second level, readers activate the meaning of the text and expand the knowledge about explicit information from the text like grammar or syntax into the textbase level. The third level is the situation model. This model arises when textbase elements are combined with elements from the readers' general knowledge.

It has been suggested that text cohesion represents an essential factor for successful comprehension (Kintsch and Van Dijk, 1978). Halliday and Hasan (1976, p. 4) defined text cohesion as "relations of meaning that exist within the text, and that define it as a text." Text cohesion can be divided into (i) local cohesion, which refers to the interrelation between smaller chunks of a text or at the sentence level and (ii) global cohesion, which refers to larger chunks of a text such as paragraphs. Text cohesion has also been found to be an important factor contributing to text comprehension (Ozuru et al., 2009). When reading a highly cohesive text, the majority of information to maintain text coherence is provided by the text itself. Less cohesive texts have only few or no connections between ideas in a given text, why readers are confronted with cohesion gaps. To bridge cohesion gaps with inferences, relevant prior knowledge is necessary, especially when text cohesion is low (McNamara et al., 1996; Singer and Ritchot, 1996; McNamara, 2001). Prior knowledge and information provided by the current text are combined to construct a situation model of the text content, which is necessary for comprehension. The

more prior knowledge a reader has, the better the text will be comprehended.

In addition to the relationship between text cohesion and comprehension, studies showed that increasing the cohesion of a text facilitates and improves text comprehension in different manner across readers with different degree of prior knowledge (McNamara et al., 1996; Graesser and McNamara, 2011). In two experiments, the role of text cohesion in the comprehension of biology texts was investigated (McNamara et al., 1996). Students were asked to read science texts and answer comprehension questions via free recall, written questions and key-word sorting tasks. Text cohesion was manipulated by adding or deleting cohesive cues to create high- and low-cohesive versions of each text without the modification of the text content. For the high-cohesive version several local and global cohesive devices were used: (1) replacing pronouns with noun phrases when the referent was ambiguous; (2) adding descriptive elaborations to link unfamiliar concepts with familiar ones; (3) adding sentence connectives to specify the relations between ideas; (4) replacing words to increase argument overlap; (5) adding topic headers; and (6) adding topic sentences to link each paragraph to the rest of the text and to the overall topic. Results indicated that readers who know little about the domain of the text benefited from high-cohesive text, whereas high-knowledge readers benefited from low-cohesive texts (reverse cohesion effect). High-cohesive texts help low-knowledge readers to bridge gaps in their background knowledge. In contrast, high-knowledge readers gained from low-cohesive texts because being induced in the generation of inferences resulted in a better text comprehension (McNamara et al., 1996). Crucially, individual differences in the ability to activate and utilize this existing background knowledge can act as mediators in the relationship between prior knowledge and reading comprehension (Woltz and Was, 2007).

Another factor influencing reading comprehension are individual differences in basic processing characteristics as e.g., the working memory capacity (WMC). In the study of Daneman and Carpenter (1980), participants performed a reading span task, a simple word span task, and a reading comprehension task. In the reading span task, participants had to read a series of sentences aloud and recall the last word of each sentence to measure WMC. The maximum number of final words that an individual could recall in correct serial order under these conditions was taken as their working memory span. In the word span task, participants had to recall sets of individual words. In the reading comprehension task, participants were given a series of passages to read silently and in the end of each passage, they were asked to answer questions about it. The results of the study indicated that low reading comprehension was related to a low WMC and that lower WMC readers have not as much capacity to integrate information from the text into a working mental model. On the other side, participants who scored a high WMC kept more information in their memory.

A further factor influencing the efficiency of reading is related to the strength of participants' attention allocation on the text by itself. This phenomenon is known as mind wandering, which means that subjects' attention may drift away from a primary task to task unrelated thoughts (TUTs) and this may occur also

when reading texts (Smallwood and Schooler, 2006). Schooler et al. (2004) assessed that ~23% of the time spent reading involves mind wandering. Many prior studies investigated the effects of mind wandering on reading comprehension performance by using the thought probe method to measure the frequency of mind wandering (e.g., Schooler et al., 2004; Smallwood, 2011; McVay and Kane, 2012b; Risko et al., 2012; Feng et al., 2013). Schooler et al. (2004) showed that participants, who read selections from *War and Peace* and completed a comprehension test after reading, exhibited lower comprehension of the text when they reported more mind wandering. As a first influential factor on mind wandering, Smallwood et al. (2009) found that experience with the topic read (prior knowledge) influenced TUTs during reading. To measure topic experience participants were asked to indicate how far they had studied the topic subjects (biology, physics, and chemistry) in school. Participants then performed attentional and reading tasks and were asked about the temporal orientation of their mind wandering episodes. One result was that the factor topic experience influenced the temporal focus of mind wandering. Especially for students with low interest in the topic, low experience with the topic was related to a prospective focus to TUTs, while high experience with the topic led them to retrospect (Smallwood et al., 2009).

In addition to prior knowledge, greater text difficulty has also been found to increase the degree of mind wandering (Feng et al., 2013; Mills et al., 2015). Feng et al. (2013) manipulated text difficulty by varying syntactic complexity. They administered 27 or 28 thought probes (depending on whether the even or the odd numbered passages constitute the easy condition). On the presentation of these thought probes, participants should indicate, if they were mind wandering during reading. The results showed that text difficulty positively correlated with the amount of mind wandering. Mind wandering not only occurred more frequently in difficult than in easy text conditions, but had a greater negative impact on performance in the difficult condition. Moreover, Mills et al. (2015) manipulated text difficulty through variations of surface (e.g., sentence length) and deep features (e.g., narrative structure) of sub-sections of the text. They found that participants significantly mind wandered more often while reading difficult sections rather than easy sections of the text.

Furthermore, recent research identified WMC as a further predictor for the occurrence of TUTs in cognitively demanding tasks like reading (McVay and Kane, 2012a,b; McVay et al., 2013). Unsworth and McMillan (2013) showed that WMC was negatively correlated to mind wandering during reading and participants with lower WMC tended to mind wander more than participants with higher WMC. Similarly, McVay and Kane (2012a,b) reported that participants with greater WMC reported fewer TUTs across several reading tasks. They argued that these participants have greater ability to adjust their attention to the task demands than individuals with low WMC and this may cause that participants with lower WMC may suffer from comprehension failures when creating a mental text representation. The significant indirect effect of WMC on reading comprehension through TUTs indicated that participants with lower WMC had more TUTs and, therefore, showed poorer reading comprehension performance (McVay and Kane, 2012b).

In order to better understand the relationship between mind wandering and attentional processes, two perspectives have been proposed (Smallwood and Schooler, 2006; McVay and Kane, 2010). First, the resource-demand theory (Smallwood and Schooler, 2006) assumes that mind wandering consumes executive resources that compete with the main task and thus attention is drawn away from the primary external task and is directed toward task independent internally generated content. In support of this view, an inverse relation between mind wandering and reading comprehension has been reported (Smallwood et al., 2008). The authors found that readers who mind wandered during reading were less likely to generate the situation model during reading and were, thus, less able to make inferences necessary for comprehension. They argued that when mind wandering occurs frequently during reading, the text is insufficiently processed to produce a correct situation model. In a similar vein, Feng et al. (2013) also argued that the successful construction of a situation model requires attentional resources and can, therefore, suppress off-task thoughts that are competing for attention. Moreover, both posit that during reading difficult texts, when participants are less successful in the construction of appropriate situation models of the text they are engaging less attentional resources, which consequently can lead to more off-task thoughts and increase the extent of mind wandering (Smallwood et al., 2008; Feng et al., 2013). With regards to working memory, this view predicts a positive relation between WMC and mind wandering—high capacity readers should have enough resources to engage in off-task thoughts without compromising reading comprehension.

Second, the so-called executive control-failure hypothesis (McVay and Kane, 2010) postulates that executive control capabilities prevents mind wandering by keeping the attention on the primary task and suppressing interference from rather spontaneously occurring TUTs that are probably triggered by (personally relevant) environmental cues (cf., Rummel and Boywitt, 2014). When executive control fails, attention is distracted from the primary task to these TUTs causing mind wandering, without consuming executive resources. This view is supported by numerous findings indicating that high-WMC individuals were less engaging in mind wandering than low-WMC individuals. As WMC reflects attention-control abilities (e.g., Kane and Engle, 2003) individuals with high WMC have more free attentional control resources to maintain their focus on the primary task and suppress TUTs. Extending this view, Rummel and Boywitt (2014) compared the relationship between WMC and mind wandering in a relatively non-demanding task (1-back) vs. a more demanding version of the same task (3-back) and found a negative relationship between WMC and mind wandering during the more difficult 3-back task and a positive relation between WMC and mind wandering during the easier 1-back task. Based on these results they postulated the so-called cognitive-flexibility hypothesis assuming that the relationship between WMC and mind wandering is dependent on task demands (Rummel and Boywitt, 2014). In more detail, high-WMC individuals engage in TUTs when task demands are low but reduce TUTs in attention-demanding tasks when these TUTs are very likely to impede performance on these tasks. However,

the authors also report overall more mind wandering in the low vs. the high demanding task version thereby contradicting previous results (Smallwood et al., 2008; Feng et al., 2013).

Both views similarly propose that mind wandering affects executive control, but differ in the way mind wandering is related to executive control. While the resource-demand theory (Smallwood and Schooler, 2006) assumes that mind wandering requires executive resources and, thus, impedes task performance, the executive-failure hypothesis (McVay and Kane, 2010) and the cognitive-flexibility hypothesis (Rummel and Boywitt, 2014) consider mind wandering as a result of executive-control failures or adaptation processes.

As outlined above there is a considerable debate about the cognitive mechanisms underlying mind wandering and its effect on reading comprehension. Regarding the influence of text difficulty both major accounts outlined above make similar predictions: more mind wandering should occur during reading difficult texts. However, both accounts make different predictions regarding the effects of prior knowledge and WMC on mind wandering. The resource-demand theory (Smallwood and Schooler, 2006) would predict more mind wandering with higher WMC and more prior knowledge while the control-failure hypothesis (Kane et al., 2007; McVay and Kane, 2010) would predict the opposite: less mind wandering with higher WMC and more prior knowledge. Therefore, in the current study we tested these assumptions by investigating the interaction of prior knowledge, WMC, and text difficulty on the amount of mind wandering and on reading comprehension performance while participants read digital texts. To our knowledge, the combined impact of these factors has not been investigated so far in studies on digital text reading. Furthermore, it is not known yet, how mind wandering affects reading comprehension with regard to the degree of text cohesion. Thus, participants in the current study were asked to read a high- or a low-cohesive version of an expository text about the copy right law, with the goal to answer question about the text after reading. We assessed the occurrence of mind wandering by presenting probes asking participants to indicate the occurrence of different types of thoughts during text reading. After text reading, participants answered reading comprehension questions about the text. The aim of the present study is to explore the combined influence of several factors previously shown to affect mind wandering and reading comprehension. More precisely, we are looking at the interaction of prior knowledge, text difficulty and WMC to inform the current debate surrounding the relationship between mind wandering and attentional processes. Further, we investigate if; (i) prior knowledge has an impact on mind wandering and reading comprehension; and if (ii) text difficulty and WMC have an impact on mind wandering in a high-level cognitive task such as reading comprehension. In order to investigate the impact of prior knowledge, we tested mind wandering and the reading performance in two groups differing in their legal knowledge. While only students from current law courses created the group of participants with a high amount of prior knowledge, students of other subjects created the group of low prior knowledge about copy right law. We predicted that a larger amount of prior knowledge

should be accompanied with less amount of mind wandering and improved reading comprehension compared to less prior knowledge (hypothesis 1). We also hypothesized that reading low-cohesive texts would lead to more mind wandering and less degree of reading comprehension (hypothesis 2 and 3). Lastly, we examined potential influencing factors such as reading times and reading comprehension, which we anticipated to influence mind wandering.

METHODS

Participants

Participants were 90 students (55 participants were women) from a variety of courses at the Martin-Luther-University Halle-Wittenberg, including psychology, sociology, medicine, and history and between the 1st and 14th semester. Out of these 30 participants were law students and were between the 3rd and 14th semester (see **Table 1**). The sample size was estimated based on effect sizes reported by Forrin et al. (2019) to be approximately $N = 93$ for a between group comparison. Due to limited availability of participants with prior knowledge (i.e., law students) we were only able to recruit 90 participants. However, this sample size is still in accordance with other studies that have used a similar

TABLE 1 | Sample characteristics.

	Non-law students <i>n</i> = 60	Law students <i>n</i> = 30	All students <i>n</i> = 90
Sex: female (%)	63.3	60.0	62.2
Age (years)	24.26 ± 0.280	23.34 ± 0.450	23.80 ± 0.365
University semester	5.73 ± 0.486	8.28 ± 0.709	7.00 ± 0.597
OSpan Score	65.86 ± 1.10	66.45 ± 1.33	66.16 ± 1.215
RSpan Score	109.03 ± 1.61	114.30 ± 1.73	111.66 ± 1.67
CK score	3.65 ± 0.100	4.12 ± 0.150	3.88 ± 0.012
RC score	7.10 ± 0.270	8.23 ± 0.235	7.66 ± 0.253
Total reading time (sec.)	1836.93 ± 544	1778.307 ± 478	1807.50 ± 511
Memory test			
Original Sentence (%)	0.667 ± 0.021	0.711 ± 0.035	0.689 ± 0.028
Surface manipulations (%)	0.333 ± 0.031	0.330 ± 0.055	0.331 ± 0.043
Textbase manipulations (%)	0.667 ± 0.038	0.770 ± 0.017	0.71 ± 0.027
False errors (%)	0.504 ± 0.022	0.562 ± 0.036	0.533 ± 0.029
WMC measures			
TRTs (%)	0.728 ± 0.021	0.752 ± 0.038	0.736 ± 0.017
Text (%)	0.462 ± 0.024	0.512 ± 0.045	0.478 ± 0.020
Text-related (%)	0.267 ± 0.018	0.235 ± 0.032	0.256 ± 0.015
TUTs (%)	0.271 ± 0.021	0.252 ± 0.039	0.265 ± 0.017
Current state (%)	0.141 ± 0.015	0.153 ± 0.030	0.145 ± 0.013
Past/future (%)	0.131 ± 0.016	0.098 ± 0.021	0.120 ± 0.012

OSpan, Operation Span; *RSpan*, Reading Span; *CK*, content knowledge; *RC*, reading comprehension; *WMC*, working memory capacity; *TRTs*, Task-related thoughts; *TUTs*, task-unrelated thoughts; values represent means ± SE.

sample size (e.g., Feng et al., 2013). Forty four participants were in the high-cohesion/easy condition, and 46 participants in the low-cohesion/difficult condition. All participants were between the ages of 18 and 33 years. The mean age of the participants was 23.80 years ($SD = 3.10$). Participants received 8 Euro/hour as compensation for their time. The mind wandering data of one participant were excluded from the analysis because of technical issues during data acquisition. Excluding the data of this participant did not impact the statistical significance of any other results.

Materials and Procedure

The entire study took place over a single 1.5h session. Participants first signed a declaration of informed consent and then provided demographic information including their gender, age, subject of study and semester. Secondly, they completed a short test to assess their content knowledge of the content domain. Afterwards, participants read the hypertext and were thought probed during reading. Immediately after they finished reading, participants answered reading comprehension questions based on the text and solved a memory test. Finally, participants completed two working memory tasks (Ospan and Rspan) to assess WMC. All procedures followed were conducted in accordance with the guidelines of the World Medical Association Helsinki Declaration of 1975. The procedures have been assessed and have been regarded as low risk. Therefore, it did not require further ethical review by an ethics committee.

Tasks

Working Memory Capacity Tasks

All participants completed two complex span tasks (operation span and reading span) to assess individual WMC. For each task, participants first completed several practice trials to ensure they understand the task demands and then completed scored trials. Both tasks were presented using PEBL (Mueller and Piper, 2013). We are aware of an ongoing debate that content-embedded tasks seem better suited for predicting reading comprehension than the span tasks due to a greater amount of variance in these comprehension tasks compared to complex span tasks (Was et al., 2011), but it was decided to use complex span tasks for the sake of better comparability with previous studies (e.g., McVay and Kane, 2012b; Unsworth and McMillan, 2013).

Operation Span (Ospan): Participants were presented with simple math operations (e.g., $4-1 = 1?$) and indicated whether the equation is true or false. After each operation, participants had to memorize an unrelated letter, which appeared for 1 s. After a series of operations and letters to memorize, participants had to recall the letters in the correct serial order by clicking the correct letters with a mouse on the computer screen. There were three trials for each list length. List length varied between three and seven letters, and the order of the list length varied randomly. Participants first practiced the task and participants whose equation verification accuracy was below 85% could not continue the task. One participant was therefore excluded from further analyses. Items were scored correctly if the item was correct and in the correct position. The score was the number of correct items in the correct position, and the total possible score

was 79. The number of correctly recalled items within each set was converted into a proportion-correct score.

Reading span (Rspan): Participants had to make judgments about the semantic correctness of a presented sentence (e.g., turtles ride the bike). After each judgment, a to-be-remembered single letter appeared for 1 s. After a series of judgements to make and letters to memorize, participants had to recall the letters in the correct serial order by clicking the correct letters. There were five trials for each list length. List length varied between three and seven, and their order varied randomly. Participants first practiced the task, and participants whose equation verification accuracy was below 85% could not continue the task and were therefore not included in further analyses. Therefore, 2 participants were excluded in WMC measures. The same scoring procedure as for the Ospan task was used. The total possible score was 129. The number of correctly recalled items within each set was converted into a proportion-correct score.

A total memory span score was computed as the overall mean proportion correct responses from the Ospan and the Rspan task. Based on this composite measure of WMC a median split of the average score was performed to categorize participants into two groups: High-WMC and low-WMC.

Content Knowledge Test

To investigate participant's knowledge about the copyright law, participants completed a paper-pencil content knowledge test about general copyright law aspects with a total of 5 single-choice questions. For each question, participants had to choose one answer out of four possible alternatives. The correct answers were added together to obtain a total score of prior content knowledge. In the easy condition the mean sum of correct answers was 3.65 ($SE = 0.100$), and in the difficult condition 4.12 ($SE = 0.150$).

Hypertext Reading

Participants read an expository hypertext about the copy right law. The text contained information about the topics copyright law, authorship, limitations, and exceptions to the copyright, the amount of copied material and infringements of the copyright law, and is currently used as training material for lecturer qualification at the Center of multimedia teaching and learning of the Martin-Luther University Halle-Wittenberg. We created two versions of the same text: A high cohesion (easy condition) and low cohesion (difficult condition) version (see **Supplement Table 1** for the full German versions). We used the same cohesion manipulations on local and global level as McNamara et al. (1996). For creating high-cohesive texts, following aspects were manipulated: (1) replacing pronouns with noun phrases, when the referent was ambiguous; (2) adding sentence connectives to specify the relations between ideas; and (3) replacing words to increase argument overlap. Global cohesion was increased by (1) adding topic headers and (2) linking each paragraph to the rest of the text and to the overall topic. For creating low-cohesive texts, the following actions were conducted: (1) using pronouns instead of noun phrases, especially when the referent was ambiguous; (2) removing sentence connectives to unlink the relations between ideas; and (3) using different words to decrease argument overlap.

Global cohesion was decreased by (1) removing topic headers and (2) changing the order of paragraphs within the text and disconnecting them from overall topic. There were 68 manipulations in total. On average, one to two manipulations on the global and about five manipulations on the local level appeared within a text segment of 500 words. The length of the high-cohesive version was 4,870 words and of the low-cohesive version 4,620 words. The texts differed in length (e.g., by removing topic headers or connectives), but not in text content. To make things clearer, an example of a translated section of the easy version of the text is: *‘The principles of good scientific work overlap with the principles of copyright law but pursue different objectives: While **scientific principles protect** “the father of the thought”, copyright law only applies if the thought meets the requirements of a protected work. The fulfillment of the requirements **of a protected work implies that scientific principles with their obligation to cite (this means stating the source of a thought) are much more comprehensive than the principles of copyright law.** Copyright law, on the other hand, has stricter requirements, **since the citation right allows an interference with the rights of the author without prior consultation of the author**’* (see **Supplement Table 1** for the German version of the full text). An example of the difficult version of the same section is: *‘The principles of good scientific work overlap with the principles of copyright law but pursue different objectives: While **science protects** “the father of thought”, copyright law only applies if the thought meets the requirements of a protected work. The fulfillment of the requirements implies **the fact that scientific principles with their obligation to cite (as a rule, this means the indication of a source) go much further than copyright.** Copyright law has stricter requirements. The citation right allows an interference with the rights of the author without **the necessity to consult the author beforehand.**’* Bold face font was used to highlight the difference between the two versions.

The average Flesch-Reading-Ease-Score was 35 in the easy and 38 in the difficult condition, indicating moderate difficulty (Schöll, 2015). The text was presented on a computer screen as several pages in black font on a white background. One text page on the computer screen contained around 500 words. Participants continued to the next page by clicking the “next”-button in the bottom right corner of the screen. Participants were given as much time as they needed to read the text. Participants were informed that they are required to complete a reading comprehension test afterwards.

Mind Wandering Probes

Participants first read a definition of mind wandering, which was used in prior studies (Smallwood et al., 2007, p. 533): “During this experiment you will be asked at various points whether your attention is firmly directed toward the task, or alternatively you may be aware of other things than just the task. Occasionally you may find as you are reading the text that you begin thinking about something completely unrelated to what you are reading; this is what we refer to as “mind wandering.” At a random interval exponentially distributed between 2 and 4 min with a mean duration of 3 min during reading the hypertext, participants were asked, what they were thinking of just before the thought probe

appeared in a pop-up window in the bottom of the screen with a beep sound (Stawarczyk et al., 2011; Unsworth and McMillan, 2013). As soon as the thought probe appeared, participants had to select an answer from four response categories by pressing the corresponding number on their keyboard: (1) thinking of the text; (2) thinking how well I’m understanding the text; (3) thinking about the current state of being; (4) having a memory in the past or something in the future (Unsworth and McMillan, 2013). To prevent confusion, the experimenter then explained the response options and the participants were given some examples for each category before starting the reading task. For response 2, an example would be “I wonder what this aspect of the text actually means” and consist of thoughts about aspects of the text (evaluative thoughts about comprehending or missing aspects), but not what was read at that moment. For response 3, an example would be “I’m hungry” and consists of thoughts about one’s current physical or emotional state. For response 4, an example would be “The party last weekend was fantastic” and consists of thoughts about events in the past or in the future. After responding to a category, participants proceeded reading the text. They could not go back to reread a page once they had clicked to the next page. Responses (1) and (2) were scored as being task-related thoughts (TRTs), responses (3) and (4) were scored as task-unrelated thoughts (TUTs). In the past, response category 2 was not unequivocally considered as a task-related (Hollis and Was, 2016). Nevertheless, when thinking about the text, there is also a processing of the text and thus an examination of it. Interfering thoughts are therefore also related to the appraisal of the current text. Based on this reasoning we consider since answer category 2 as reflecting task-related thoughts. However, because of the ongoing debate we excluded this response category from all statistical analysis. In addition, McVay and Kane (2009) and Stawarczyk et al. (2014) reported, the “current state of being” experiences represent around 50% of mind wandering episodes. McVay et al. (2013) have also shown that a negative correlation between the mind wandering frequency and the WMC is less consistent if the category “current state of being” is not included in the analyses. They also demonstrated no or only a slight correlation between thoughts related to the past or future and WMC. For these reasons we chose to only analyse TUTs related to “current state of being.” For this response category the proportion of TUT-responses was computed, with a higher proportion indicating more mind wandering. In addition, reading times were recorded for the hypertext.

Reading Comprehension Test

To investigate how well participants understood the text, participants completed a paper-pencil reading comprehension task about the text content with a total of 12 single-choice questions. For each question, participants had to choose one answer out of four possible alternatives. Scores were the sum of correctly answered questions. In the easy condition the mean sum of correct answers was 8.43 ($SE = 0.143$) and 6.89 ($SE = 0.364$) in the difficult condition.

Sentence Recognition Test

The processing of meaning of a text underlies memory for content and the situational model supports an organizational

memory structure for content (Ericsson and Kintsch, 1995). In this sentence recognition test, participants had to distinguish whether a sentence occurred in the hypertext via a true or false key-press. There were 16 sentences in total, 8 sentences were original text sentences and 8 sentences were manipulated on surface or textbase structure. An original sentence of the text would be: “*Copyright law protects the author’s relationship to his work.*” Manipulations on surface structure contained the shifting of a clause within the base sentence to a new position, so that the surface sentence structure changed, e.g., “*The relationship of the author to his work is protected by copyright law.*” Manipulations on textbase structure contain the replacing of a proposition in the base sentence, so that the meaning of the text altered, e.g., “*Copyright law regulates the relationship between the author of a work and the user of the same.*” Presentations of sentences were randomized for each participant. For statistical analysis, percent correct responses were calculated.

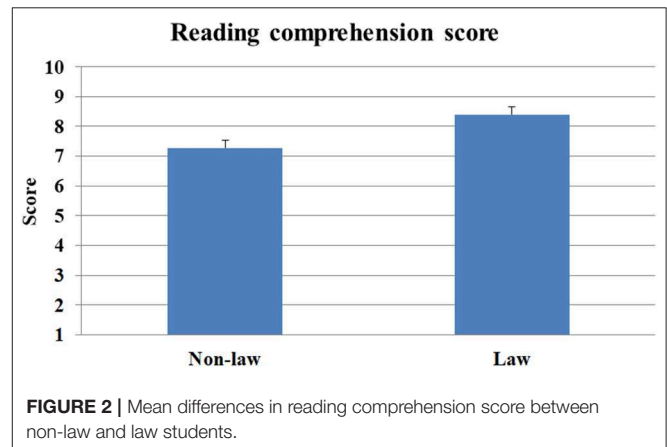
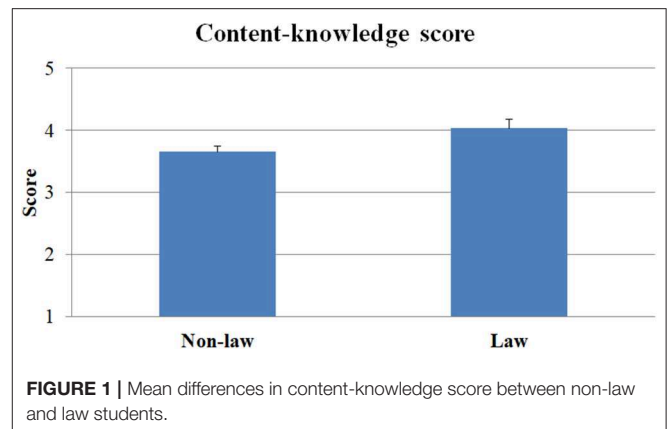
Statistical Analyses

All statistical analyses were carried out using IBM SPSS Statistics 23.0. An alpha value of 0.05 was adopted for all significance testing. Estimated effect sizes are reported using partial eta squared (η_p^2) or Cohen’s d , respectively. *Post-hoc* tests were adjusted using Bonferroni correction. Analyses of variance (ANOVAs) were conducted for the analyses. In a first analysis, we conducted independent sample t -tests and compared law and non-law students’ engagement with TUTs and on their performance in the content-knowledge test. For the second analysis, we conducted a three-way ANOVA to analyse the mind wandering values depending on the between-subject factors content knowledge (law, non-law), text difficulty (easy difficult) and WMC (low, high). In a third analysis, we compared overall reading times between difficult and easy texts and conducted another three-way ANOVA to analyse comprehension performances depending on the between-subject factors prior knowledge (law, non-law), text difficulty (easy, difficult) and WMC (low, high). Finally, we conducted a Pearson’s correlation analysis between the related values.

RESULTS

First Hypothesis: Impact of Prior Knowledge on Mind Wandering and Reading Comprehension

First, the effect of prior knowledge was assessed by comparing law and non-law students on their performance in the content-knowledge test. Therefore, the number of correct items was counted. As expected, law students achieved a higher score in the content-knowledge test than non-law students [Figure 1, $t_{(88)} = -2.137$, $p < 0.05$, $d = 0.46$]. Second, law and non-law students were compared on their performance in the reading comprehension test. Again, the number of correct item was counted. Law students exhibited better reading comprehension scores compared to non-law students [Figure 2, $t_{(88)} = -2.575$, $p < 0.05$, $d = 0.55$]. However, the learning gain, i.e., the increase



in knowledge from pre to post test was similar in both groups [$t_{(88)} = 1.637$, $p = 0.11$, $d = 0.21$], suggesting that prior knowledge did not benefit reading comprehension.

Contrary to our hypothesis, we could not find any significant effect of prior knowledge on the proportion of mind wandering or the sentence recognition test [proportion of mind wandering TUTs: $t_{(87)} = 0.478$; proportion of the TUTs-category “current state of being”: $t_{(87)} = -0.387$; proportion of the TUTs-category “something in the past/future”: $t_{(87)} = 1.150$; proportion of correctly recognized manipulated sentences on surface: $t_{(87)} = 0.099$; or textbase level: $t_{(87)} = -1.788$; all $p > 0.05$]. Thus, as law and non-law students did not differ on relevant variable apart from their knowledge about copyright law, all subsequent analyses were carried out on the whole sample.

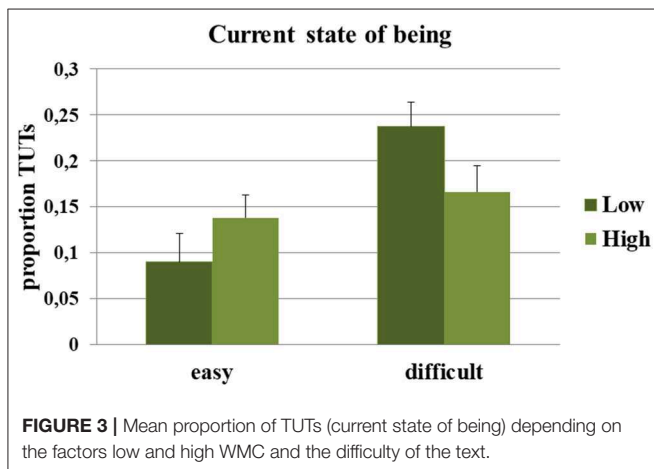
Second Hypothesis: Impact of Text Cohesion on Mind Wandering

Looking at the mean proportion of the easy and difficult text condition, participants experienced more TUTs (30%) in the difficult than in the easy text condition (23%, see Table 2). The analysis of mind wandering (current state of being) showed a significant main effect [$F_{(1, 81)} = 5.525$, $p < 0.05$, $\eta^2 = 0.064$]. There was no significant main effect of prior knowledge [$F_{(1, 81)}$

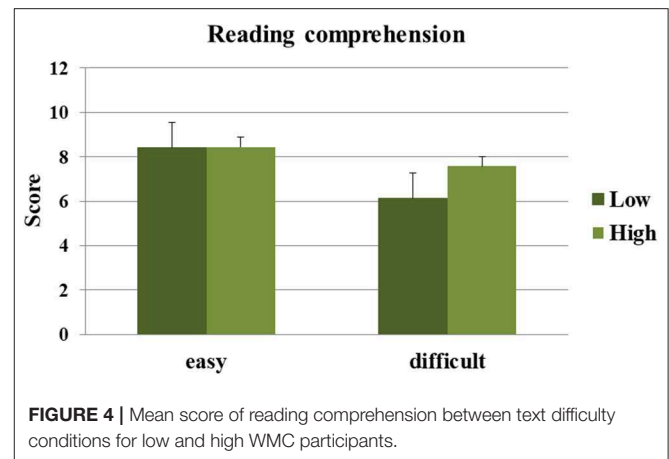
TABLE 2 | Mean proportion of mind wandering, and comprehension scores for easy and difficult text condition.

Measure	Easy condition	Difficult condition
Thought probes		
Task Related Thoughts (TRTs)	0.77 (0.16)	0.70 (0.18)
Text	0.49 (0.19)	0.47 (0.22)
Text-related thoughts	0.28 (0.13)	0.23 (0.16)
Task unrelated thoughts (TUTs)	0.23 (0.16)	0.30 (0.18)
Current state of being	0.11 (0.10)	0.18 (0.15)
Something in the past/future	0.12 (0.13)	0.12 (0.11)
Comprehension		
Reading comprehension score	8.43 (0.95)	6.89 (2.47)
Proportion correctly recognized surface manipulations	0.29 (0.21)	0.36 (0.28)
Proportion correctly recognized textbase manipulations	0.75 (0.25)	0.67 (0.29)

TRTs, task-related thoughts; TUTs, task-unrelated thoughts.

**FIGURE 3** | Mean proportion of TUTs (current state of being) depending on the factors low and high WMC and the difficulty of the text.

$= 0.455, p > 0.05, \eta^2 = 0.006$], or WMC on TUTs [$F_{(1, 81)} = 0.890, p > 0.05, \eta^2 = 0.011$]. We could not find a significant interaction between prior knowledge, text difficulty and WMC [$F_{(1, 81)} = 0.103, p > 0.05, \eta^2 = 0.001$], however, we did observe a significant interaction of text difficulty and WMC on TUTs [$F_{(1, 81)} = 5.369, p < 0.05, \eta^2 = 0.062$; see **Figure 3**]. Nevertheless, overall mind wandering rates (TUTs) were not significantly different across easy and difficult texts [$t_{(87)} = -1.624, p > 0.05$]. However, the independent t -test revealed significant differences between easy and difficult condition for the mind wandering category “current state of being” [$t_{(87)} = -75.546, p < 0.05$]. *Post-hoc* analyses were conducted to compare WMC effects separately for easy and difficult condition. We could not find a significant difference comparing WMC effects for the easy [$t_{(42)} = -1.256, p > 0.05$], but for the difficult condition [$t_{(43)} = -2.246, p = 0.030$] indicating that participants with low WMC showed more mind wandering only when reading difficult texts (see **Figure 3**).

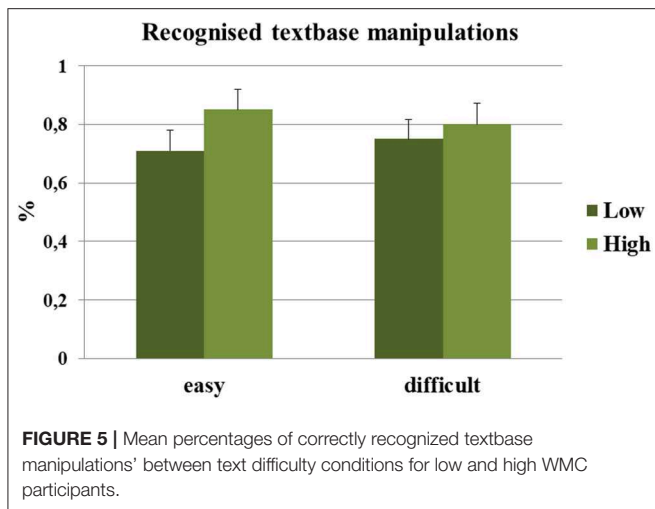
**FIGURE 4** | Mean score of reading comprehension between text difficulty conditions for low and high WMC participants.

Third Hypothesis: Impact of Prior Knowledge, Text Cohesion, and WMC on Reading Comprehension

In general, it should be said that the overall reading times (in seconds) of the difficult texts ($M = 1,739, SD = 451$) was not statistically different from the overall reading times of the easy texts [$M = 1,876, SD = 571; t_{(87)} = 1.247, p = 0.65$]. This indicates that text difficulty had not an effect on reading times.

Reading comprehension was measured by a reading comprehension test. As can be seen in **Table 2**, the difficult text condition yielded lower reading comprehension scores compared to the easy text condition. On average, participants answered 70.25% of the reading comprehension questions correctly for the easy texts and 57.41% for the difficult texts. A three-way ANOVA revealed a significant main effect of prior knowledge on reading comprehension [$F_{(1, 82)} = 7.905, p < 0.05, \eta^2 = 0.088$; **Figure 2**]. Furthermore, there was a significant main effect of text difficulty on reading comprehension [$F_{(1, 82)} = 11.651, p < 0.001, \eta^2 = 0.124$], such that the comprehension score was lower for the difficult condition (**Figure 4**). There was no main effect of WMC on the reading comprehension score [$F_{(1, 82)} = 4.586, p = 0.229, \eta^2 = 0.018$], and no significant three-way interaction between prior knowledge, text difficulty and WMC on the score [$F_{(1, 82)} = 0.322, p = 0.572, \eta^2 = 0.004$].

To further evaluate the build-up of the situation model, we also assessed memory for the text. This was done separately for the recognition of sentences that were manipulated on the surface or textbase. As indicated in **Table 2**, participants in the difficult condition correctly recognized less textbase manipulations (67%) than participants in the easy condition (75%). In the easy condition, participants recognized 29.6% of the surface manipulations correctly while those in the difficult condition correctly recognized 36.7% of the surface manipulations. While there was no significant main effects of text difficulty [$F_{(1, 85)} = 2.004, p = 0.156, \eta^2 = 0.053$] on the correct recognition of textbase manipulations a significant main effect of WMC [$F_{(1, 85)} = 4.042, p < 0.05, \eta^2 = 0.045$] and a significant interaction between text difficulty and WMC [$F_{(1, 85)} = 4.042, p < 0.05, \eta^2 = 0.045$] were revealed (**Figure 5**). Looking



at the effect separately for the easy and difficult condition, there was a significant effect of WMC on the correctly recognized manipulated textbase sentences [$F_{(1,43)} = 7.814, p = 0.008, \eta^2 = 0.154$] in the difficult condition. The same ANOVAs conducted on correct statements and for the correctly recognized surface manipulations did not reveal any significant main or interaction effects (all $p > 0.05$).

Relationship between mind wandering, reading comprehension, and reading times.

In order to assess the relationship between the amount of mind wandering and reading performance, we conducted a Pearson's correlation analysis between the related values. There was no indication for a relationship between mind wandering and reading comprehension score as we did not observe a significant correlation between mind wandering rates and reading comprehension score ($r = -0.04, p = 0.29$). However, the analysis indicated a significant positive correlation between overall reading times and the proportions of mind wandering directed to something in the past/future ($r = 0.29, p < 0.05$), which indicates that the larger number of TUTs the longer it took participants to read the text. In addition, the frequency of thinking about the text was not correlated with reading comprehension score ($r = 0.178, p = 0.095$).

DISCUSSION

The goal of this study was to explore the combined influence of several factors (prior knowledge, text difficulty and WMC) previously shown to affect mind wandering and reading comprehension. In order to investigate the impact of prior knowledge, we tested mind wandering and the reading performance in two groups differing in their law knowledge. While law students created the group of participants with a high amount of prior knowledge, students of other subjects created the group of low prior knowledge about copy right law. We predicted that a larger amount of prior knowledge should be accompanied with less amount of mind wandering

and improved reading comprehension compared to less prior knowledge (hypothesis 1). We also hypothesized that reading low-cohesive texts would lead to more mind wandering and less degree of reading comprehension (hypothesis 2 and 3). Lastly, we examined potential influencing factors such as reading times and reading comprehension, which we anticipated to influence mind wandering.

Interestingly, prior knowledge did not have an impact on mind wandering, but on reading comprehension. We could not find any significant differences in mind wandering between law and non-law students, except for the content knowledge and the reading comprehension. Law students yielded a higher score in the content-knowledge test and reading comprehension test, but they did not engage more in TUTs compared to non-law students when reading texts about copyright content. Contrary to previous findings (Smallwood et al., 2009; Kopp et al., 2016), it seems that WMC and textual difficulty, rather than prior knowledge, were the most decisive factors needed to successfully build a situation model, which in turn fosters the suppression of mind wandering by increasing the focus of attention on the text. Similarly, previous studies showed an effect of prior knowledge with text comprehension, but not with TUTs (Unsworth and McMillan, 2013). The content-knowledge test of a further study did not show a direct effect of prior knowledge (Magliano et al., 2002). Only Magliano's et al. (2002) sorting test did show an effect, which can be best explained by the clear structure of the relevant texts.

The present study demonstrated that mind wandering did occur more frequently when participants read difficult rather than easy texts. In the difficult text condition, more TUTs regarding the current state of being appeared. This is in good agreement with previous findings (Smallwood and Schooler, 2006; Feng et al., 2013; Mills et al., 2015) and with earlier assumptions that "current state of being" experiences are mainly responsible for mind wandering episodes (McVay and Kane, 2009; Stawarczyk et al., 2014). In addition, this finding is in line with both, the resource-demand theory (Smallwood and Schooler, 2006) and the control-failure hypothesis (Kane et al., 2007; McVay and Kane, 2010). The resource-demand theory assumes that mind wandering is more frequent when readers have difficulties constructing a situation model of the text (Kintsch and Van Dijk, 1978; Smallwood et al., 2008). As suggested by the lower comprehension scores in the difficult condition, a decreased text cohesion interferes with readers' ability to construct a situation model from the text. This would imply that participants have no resources available to suppress TUTs.

The occurring mind wandering is further promoted by individual differences in WMC and therefore in the ability to control attention while reading (McVay and Kane, 2010). High-WMC individuals are assumed to have better executive control capabilities than low-WMC individuals and might have more free resources to perform the reading task and suppress spontaneously occurring mind wandering. In addition, as Rummel and Boywitt (2014) postulated, the relation between WMC and mind wandering is dependent on the task demands, meaning that individuals with a high WMC should decrease

mind wandering rates in demanding tasks like reading low cohesive, i.e., difficult texts. In contrast, these individuals would have sufficient attentional control resources to read high cohesive, simple texts and engage in TUTs simultaneously. Our results that high WMC participants did not exhibit more TUTs than low WMC participants in the easy condition seems to contradict this notion.

In addition, text difficulty and WMC also had an impact on reading comprehension. If you look at the results descriptively, participants in the easy condition showed a better reading comprehension score than participants in the difficult condition. This is consistent with previous studies, which showed that increasing the cohesion of a text helps to construct a situation model of the text and therefore facilitates and improves text comprehension for many readers (McNamara et al., 1996; Graesser and McNamara, 2011). Besides, participants with a low WMC scored particularly lower in the reading comprehension test in the difficult condition than participants with a high WMC. Additionally, we could find the same interaction effect for the correct recalled textbase manipulations. Participants with a low WMC could significantly recall less manipulated textbase sentences correctly than participants with a high WMC in the difficult condition. Together, these results indicate that lower-WMC readers do not have much capacity to integrate information from the text into a working mental model (Daneman and Carpenter, 1980). With a low WMC, individuals showed decreased executive control capabilities and have fewer resources to perform a primary task (McVay and Kane, 2010). We speculate that low WMC participants might have difficulties to inhibit irrelevant information and access related information from working memory, especially when text complexity is high.

In sum, our results do not fully support either of the two theoretical accounts but are in most agreement with the cognitive-flexibility hypothesis (Rummel and Boywitt, 2014) stating that high-WMC individuals engage in TUTs when task demands are low but reduce TUTs in attention-demanding tasks when these TUTs are very likely to impede performance on these tasks. Based on the present results we propose an extension of the existing models (Smallwood and Schooler, 2006; McVay and Kane, 2010; Rummel and Boywitt, 2014) that mind wandering occurs whenever the available resources of the reader (WMC, prior knowledge, etc.) do not match the task demands. In contrast to the cognitive-flexibility hypothesis (Rummel and Boywitt, 2014) our resource-demand-matching view states that low availability of cognitive resources, for instance imposed by high text difficulty in a reading comprehension task or due to low WMC leads to more mind wandering as does high availability of these cognitive resources exceeding the demand. Within this view, we argue that prior knowledge could potentially free up processing resources as prior knowledge is combined with the current text to benefit the construction of the situational model (cf., Unsworth and McMillan, 2013). However, if this benefit is rather small, as it is the case in the present study, the effect of prior knowledge on mind wandering is negligible.

Previous studies have demonstrated that increased amount of mind wandering impedes on text comprehension (e.g., Schooler et al., 2004). In the present study increased amount of mind

wandering did not reduce text comprehension but did extend the reading time indicated by a positive correlation between reading time and future/past-oriented TUTs. Reading times were longer when participants mind wandered more often about their future or their past. This is consistent with prior studies, which showed that slower reaction times are caused by attention failures in engaging tasks (Unsworth et al., 2010; McVay and Kane, 2012a). This suggests that participants who are aware of their mind wandering (or being made aware by the thought probe technique) tried to compensate for this attention failure and the resulting lack of understanding by reading some passages of the text again. The present results suggest another factor that influences the relationship between the amount of mind wandering and reading comprehension. The frequency of thinking about the text was marginally correlated with the reading comprehension score, indicating that more elaboration of the text leads to a better understanding of the text, without prolonging the reading time. Thus, whether mind wandering impedes on text comprehension seems to depend on the engagement of compensatory processes: either extending reading times and/or more elaborative thoughts about the content of the text. The precise role of such compensatory processes remains to be elucidated.

The study has limitations. A potential limitation of our study could be that we did not measure situational interest, because we primarily wanted to examine the characteristics of the text. Prior research has shown a negative relation between text interest and mind wandering (Giambra and Grodsky, 1989; Smallwood et al., 2009; Dixon and Bortolussi, 2013; Unsworth and McMillan, 2013). Giambra and Grodsky (1989) found that mind wandering was not linked to text difficulty, but to text interest. They showed that the more one is interested in the current topic of the text the better their attention is focused on the text. It could be that mind wandering occurs more often during reading difficult texts, but only for less interested participants. However, we cannot fully rule out this potential confound. In addition, situational interest could also have dampened the influence of prior knowledge on mind wandering. Miller and Kintsch (1980) hypothesized that situational interest was low when prior knowledge was low. According to Tobias (1994), interest can be helpful for readers with prior knowledge, but not for low-knowledge readers and the presentation of few new items leads to optimal interest. The reason why we did not find an effect of prior knowledge on mind wandering could be due to the lack of interest. Therefore, the role of interest should be considered in future studies.

CONCLUSION

The present findings provided novel insights into processing attention during reading texts by investigating the interaction of text difficulty, working memory capacity and prior knowledge on mind wandering and reading comprehension while reading digital texts. The present study has provided evidence that the impact text difficulty had on mind wandering and reading comprehension was modulated by WMC. Participants with

lower WMC exhibited more frequent mind wandering than high-WMC participants solely when reading low-coherent texts. In addition, high-WMC participants outperformed low-WMC participants on all measures of text comprehension. In this study, we have attempted to extend the existing theories (resource-demand theory, control-failure hypothesis, cognitive-flexibility theory) by new aspects and to concretize them in parts.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary material**.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TSchur, TSchub, and BO were involved in planning and developed the theory. TSchur and BO designed experiments, processed the experimental data, and performed the analysis. TSchur carried out the experiments. TSchub and BO supervised

the research and aided in interpreting the results. TSchur drafted the manuscript with support from all authors and designed the figures. All authors discussed the results and commented on the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2020.00026/full#supplementary-material>

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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