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Concurrent prospective memory task increases mind wandering during online reading for difficult but not easy texts

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Abstract

Many prior theories have tried to explain the relationship between attentional processes and mind wandering. The *resource-demand matching view* argues that a mismatch between task demands and resources led to more mind wandering. This study aims to test this view against competing models by inducing mind wandering through increasing the level of demands via adding a prospective memory task to cognitively demanding tasks like reading. We hypothesized that participants with a second task still in mind (unfinished group) engage more in task-unrelated thoughts (TUTs) and show less text comprehension compared to participants who think a second task is finished (finished group). Seventy-two participants had to study 24 items of a to-do list for a recall test. After a first cued recall of ten items, participants were either told that a second task was finished or that the recall was interrupted and continued later. All participants then started reading an easy or difficult version of the same unfamiliar hypertext, while being thought probed. Text comprehension measures followed. As expected, participants in the unfinished group showed significantly more TUTs than participants in the finished group when reading difficult texts, but, contrary to our assumptions, did not show better text comprehension measures when reading difficult text. Nevertheless, participants compensate for the influence of the second task by reading longer, which in turn has a positive effect on their reading knowledge. These findings support the resource-demand-matching model and thus strengthen assumptions about the processing of attention during reading.

Keywords Attention · Reading · Mind wandering

Introduction

Mind wandering is a pervasive daily phenomenon of mental activity in which attention engages with thoughts that are unrelated to external demands (Smallwood, 2013), and plays a critical role for performance in many cognitive tasks (e.g., reading, listening to lectures, driving). For example, you can think of your shopping list when solving a text task or conducting other acitivities in parallel. In the past, different perspectives have been proposed to explain the relationship between attentional processes and mind wandering (McVay & Kane, 2010; Schurer et al., 2020; Smallwood & Schooler, 2006).

To begin with, Smallwood and Schooler (2006) proposed the *resource-demand theory*, which assumes that attention is distracted from the primary task to task-unrelated thoughts (TUTs) and therefore mind wandering consumes executive resources that compete with the main task. They argue further that individuals with high resources are less likely to exhibit impaired performance when experiencing mind wandering than those with low resources because they can easily allocate these resourcs between TUTs and task performance. In support, Smallwood et al. (2008) showed that readers exhibiting more mind wandering episodes during reading were less able to build situation models (integrated mental representations) from the text. Furthermore, a study by Feng et al. (2013) showed that attentional resources

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devoted to the successful construction of a situation model help to suppress TUTs. Feng et al. (2013) showed that difficult texts lead to problems in building a situation model and therefore bind fewer attentional resources, which in turn lead to mind wandering. This model implies that mind wandering occurs when it is too demanding or, looked at the other way around, more mind wandering leads to lower performance (e.g., to a low build-up of a situation model). However, this model does not really make any statements about the available resources, like differences in working memory capacity (WMC). As an extension of this view, the context regulation hypothesis (Smallwood & Andrews-Hanna, 2013) further suggests that the occurrence of mind wandering can be actively regulated depending on the task context. The relationship between psychological well-being in terms of mood and self-generated thoughts is argued to depend on an individual's ability to regulate the content of their thoughts (Smallwood & Andrews-Hanna, 2013). That is, in easy tasks more mind wandering is allowed because it is conducive to well-being and in difficult tasks it tends to be inhibited because it interferes with task processing. Context seems to play an important role for understanding different thinking patterns and it causes abilities such as WMC to help suppress thoughts outside of the task when a subject is motivated to focus on an ongoing task, which is also in accordance with recent neural evidence suggesting the context-dependent occurrence of mind wandering (Turnbull et al., 2019).

In contrast, the *control failure x concerns hypothesis* (McVay & Kane, 2010) postulates that executive control capabilities prevent mind wandering by keeping the attention on the primary task and suppressing interference from rather spontaneously occurring TUTs that are activated by environmental cues and do not consume executive resources. Consequently, individuals with greater executive attention abilities (i.e., with more WMC) will have more attentional control resources to stay focused on a task while suppressing TUTs (McVay & Kane, 2009). Individual differences in the propensity to mind wander are jointly determined by cognitive ability and by context, i.e., by the presence of personally salient concerns that interfere with task focus. A person's current concerns may therefore automatically activate off-task thoughts, and failure to maintain attention on a current task then leads to mind wandering. This correspondends to an additional cognitive load that, like the actual task, ties up resources and therefore leads to more TUTs as well as determines the content of these TUTs. In support of their view, McVay and Kane (2012a, 2012b) showed that participants with greater WMC reported less mind-wandering episodes during reading tasks and showed better reading comprehension performance than participants with lower WMC. They proposed that with a greater WMC, participants are more able to adjust their attention to the task demands, whereas participants with a lower WMC were less able to create a mental model of the text. This was also supported and extended by the *cognitive-flexibility hypothesis* of Rummel and Boywitt (2014), according to which cognitive control is not only needed to inhibit TUTs when another task is performed. Instead, the authors proposed that the relationship between WMC and mind wandering is dependent on task demands: individuals with a greater WMC engage in TUTs when task demands are low and reduce TUTs when tasks demands are attention-demanding. People with a greater WMC tend to be more effective in their allocation of cognitive control abilities (Rummel & Boywitt, 2014) – they can better afford to let their mind wander from a task when attentional demands are low but are also more able to stay focused on a task when they need to. The *control failure x concerns hypothesis* suggests that more resources (e.g., WMC) lead to less mind wandering or, on the other hand, few free resources lead to more mind wandering. In addition, the *cognitive-flexibility hypothesis* states that individuals with more available resources are better able to regulate TUTs. However, this view is not explicit about individuals with low available resources.

Capitalizing on certain aspects to explain mind wandering, all the above views propose that mind wandering affects executive control but differ in the way mind wandering is assumed to be related to executive control. While the *resource-demand theory* (Smallwood & Schooler, 2006) assumes that mind wandering requires executive resources and therefore impedes task performance, the *control failure x concerns hypothesis* (McVay & Kane, 2010) and the *cognitive-flexibility hypothesis* (Rummel & Boywitt, 2014) consider mind wandering as a result of executive-control failures or adaptation processes. Both theories thus make opposing predictions and cannot comprehensively explain the findings that support the respective other theory. Crucially, each of these models is based on findings regarding different fractions of potential factors influencing mind wandering.

To better account for the existing data, we took a more comprehensive approach considering multiple factors influencing mind wandering like task demands and available cognitive resources, but also performance aspects, and proposed in a prior study an extension of the existing models, the so-called *resource-demand-matching view* (Schurer et al., 2020). We suggested that mind wandering occurs whenever the available cognitive resources of an individual (WMC, prior knowledge, etc.) do not match the task demands. We assume that cognitive resources are primariliy allocated to the main task first. Crucially, we assume mind wandering to be a spontaneously occurring but resource-demanding process that individuals may engage with if their cognitive resources exceed the current task demands or cannot avoid if task demands surpass the available resources. In other words, our *resource-demand-matching view* states that low availability of cognitive resources, for instance due to low WMC with high demands imposed by high text difficulty in a reading comprehension task leads to more mind wandering as does high availability of these cognitive resources exceeding the demand of an easy-to-comprehend text. Unlike previous models (McVay & Kane, 2010; Rummel & Boywitt, 2014; Smallwood et al., 2021; Smallwood & Schooler, 2006) assuming a more or less uniform relationhip between task demands and available cognitive resources to induce mind wandering, although individual differences in factors like WMC are assumed to moderate this relationship, our model predicts an interaction between the two.

To test the predictions made by different models, the present study increased the cognitive demands capitalising on findings demonstrating that unfulfilled tasks and goals remain persistent in the mind and, thus, present additional cognitive demands for ongoing task processing (Zeigarnik, 1927). In the original study (Zeigarnik, 1927), participants were asked to complete a series of separate, simple tasks like solving puzzles, making clay figures, or completing math problems. Half of the tasks were interrupted before the participants could complete them. Interestingly, participants recalled details of the interrupted tasks 90% better than details of uninterrupted tasks. It was also suggested that failing to finish a task leads to an underlying cognitive tension, which leads to more mental effort and rehearsal to keep focused on the task. Only when the task is finally finished does the mind let the effort go.

A former study included mind-wandering aspects in their investigations of the Zeigarnik effect (Steindorf & Rummel, 2017). The authors implemented this task as a prospective memory task (PM task). In their study, participants had to study and remember a grocery shopping-list for a prospective memory (PM task) test. After the first recall phase (half of the shopping list items) participants in a finished condition (FC) were told that they did not urgently need the remaining items, that the PM task was finished, and that they would now work on a different task (two-back task). In contrast, participants in an interrupted condition (IC) were told that they now must work on a different task and, therefore, need buy the remaining items later (i.e., to finish the PM task). Both groups of participants were thought probed during the two-back task to assess mind wandering and had then to complete the second recall phase. The group of participants interrupted during the recall of a shopping list showed more TUTs related to this secondary recall task during the performance of a two-back task than a group of participants who were told that the recall task is finished before commencing the two-back task. According to Steindorf and Rummel (2017), mind wandering can be controlled by second tasks in mind, which could be beneficial. This implies an additive effect and shows that mind wandering should not depend on the difficulty of the primary task. In contrast, Rummel et al. (2017) showed lower TUT rates when a PM intention (to respond to members of a presented semantic category) was embedded during an ongoing task (lexical decision task) as opposed to processing the ongoing task alone. In this case, PM requirements did not add cost to the ongoing task, but instead promoted thoughts to be focussed on the ongoing task. Taken together, these studies nicely demonstrate a strong connection between prospective memory requirements and mind wandering (see Kvavilashvili & Rummel, 2020, for review).

As in our previous study (Schurer et al., 2020), we also manipulated text difficulty based on Kintsch and Van Dijk's (1978) model of text comprehension allowing for a finer grained approach to disentangling the views introduced above. Crucially, text cohesion is an essential factor for successfully constructing the situation model from the text, and thus for text comprehension, which is why we manipulated text cohesion by increasing or decreasing text cohesion (see Schurer et al., 2020). Previous studies showed that a higher level of text cohesion improves text comprehension (Graesser & McNamara, 2011; McNamara et al., 1996; Schurer et al., 2020). We wanted to investigate the induction of mind wandering by a PM task in a more complex primary-task situation than Steindorf and Rummel (2017). Accordingly, we chose a similar task to tie up resources and combined it with easy and difficult texts. Thus, participants in the current study were first asked to study to-do list items for a following recall test. Participants were told either that the recall test was over or would be continued at a later time after ten items had been queried. After the first recall, the participants read a high- or a low-cohesive version of an expository text about the copyright law, with the goal to answer questions 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. Next, the second recall of another ten to-do-list items followed. Lastly, participants completed WMC measures.

In accordance with the assumption of our model (Schurer et al., 2020), we assume that an interaction of the PM task and text difficulty has an impact on TUTs and reading comprehension, making our model the only one that predicts the interaction. We predicted an interaction of text difficuty (easy vs. difficult) × PM task (finished vs. unfinished). It was hypothesized that participants having a second task in mind (prospective memory task; PM task) experience more TUTs than participants who think a second task is finished when reading difficult texts. We also predicted that participants show a worse text comprehension when they have a second task still in mind when reading difficult texts. Further, we assume that there are no differences between the two groups

Table 1 Chi-square test (sex) and independent t-test for sample characteristics of the unfinished versus the finished group

	All students $n = 72$	Unfinished group $n = 36$	Finished group $n = 36$	Test statistics (χ^2/*T*-value)	*p*-value
Sex: female (%)	68.05	69.40	66.70	.064	.800
Age (years)	23.86 (.388)	23.92 (.532)	23.81 (.580)	.142	.887
University semester	7.32 (.1.37)	5.83 (.643)	8.81 (2.66)	-1.087	.281
OSpan Score	63.85 (1.26)	64.08 (1.65)	63.61 (1.92)	.186	.853
RSpan Score	109.70 (1.44)	109.60 (2.36)	109.81 (1.72)	-.071	.944
CK score	3.79 (.156)	3.81 (158)	3.78 (.155)	.125	.901
Total reading time (s)	1758.54 (63.64)	1740.03 (97.53)	1777.06 (86.14)	-.289	.773

OSpan operation span, *RSpan* reading span, *CK* content knowledge. Values represent means, SE given in parentheses

(unfinished, finished) with respect to WMC. According to our model, if the demands are below the available resources (see also Schurer et al., 2020), a matching of resources is more likely to occur, but if the demands are above the available resources, the equilibrium is shifted and more demands than resources are available. Therefore, in the difficult text condition, there should be a mismatch between resources and demands, and, based on our model, more mind wandering.

Methods

Participants

Participants were 72 students (49 female) across several courses at the Martin-Luther-University Halle-Wittenberg. We determined the size of our participants' sample according to previous PM studies investigating mind wandering with total sample sizes from $N = 55$ (Steindorf & Rummel, 2017), $N = 68$ and $N = 61$ (Scullin et al., 2018), $N = 73$ (Masicampo & Baumeister, 2011) up to $N = 104$ (Rummel et al., 2017) participants. To achieve a comparable statistical power, we followed previous studies with comparable participant sample sizes (Rummel et al., 2017; Scullin et al., 2018; Steindorf & Rummel, 2017) for a comparison between two groups (see below for further details).[1]

Detailed sample characteristics can be found in Table 1. All participants were between 18 and 32 years old and were native speakers of German. The mean age of the participants was 23.86 years ($SD = 3.29$). All particiants were pseudo-randomly assigned to the different groups/conditions to ensure equal group sizes and gender distributions. Thus, there were 36 participants each in the finished and the unfinished group. The experimental protocol conformed tenets of the Declaration of Helsinki and written informed consent was obtained from each participant before the commencement of the study. The study was approved by the ethics committee of the Deutsche Gesellschaft für Psychologie (DGPs). Participants received 12 Euro as compensation for their time.

Materials and procedure

We adopted the procedure of our previous study (Schurer et al., 2020) with some deviations. The entire study was conducted in a single 2.0-h session. Participants signed a consent form and provided demographic information including gender, age, study course, and semester. Then, they completed a short content knowledge test to assess their prior knowledge of the content domain, followed by a PM task. In the PM task, participants were presented with the following scenario: *The semester break is due, and they are to complete 24 tasks that they have put on a to-do list. They should now remember the tasks of the to-do list.* After the study phase, ten items of the to-do list were recalled. Half of the participants were informed that they had to move on to the next task and that another ten items of the to-do list would be recalled at a later point in time (unfinished group) or that the recall had ended, and they had to move on to the next task (finished group). Afterwards, participants received detailed instructions for the reading task and the thought-probing procedure. Then, they read a hypertext about the copyright law and were presented with thought probes while reading, answered reading comprehension questions based on the text, and took part in a memory test. Now the second recall of the remaining ten to-do list items followed for all participants. Finally, the participants completed two working

[1] The adopted size of our participant sample would be consistent with an a priori power analysis with G*Power (Faul et al., 2007) for ANCOVAs assuming a medium to large effect size ($f = .34$). This effect sized was based on collapsing the individual effect sizes observed in comparable previous studies, for example, Masicampo and Baumeister (2011), $f = .36$; Steindorf and Rummel (2017), $f = .46$; Rummel et al. (2017), $f = .22$, and assuming a standard two-tailed alpha value ($p < .05$) at 80% power, which results in a required sample size of N = 68. We return to the discussion of the sample size and corresponding power issues of the present study compared to other studies in the *Limitation* section of the *General discussion*.

memory tasks (Ospan and Rspan) to assess their working memory performance. Mind wandering was not collected in the WMC tasks because their duration was too short to generate meaningful statements about TUTs. Furthermore, WMC was only included as a covariate in the analyses and not as a whole experiment as previous studies (e.g., Mrazek et al., 2012).

Tasks

Prospective memory task

In the PM task, participants studied 24 to-do list items; four of them were used as buffer items (two items as primacy, two items as recency buffer items during both recall phases). The items included typical activities that students engage in during their semester breaks (e.g., paying semester fees, creating a timetable for the upcoming semester). Participants were asked to learn the to-do list items in a random order for 2,000 ms each followed by a 500-ms inter-stimulus interval. Secondly, we created two recall phases consisting of ten test items each, which the participants had to recall in the two recall phases on a sheet of paper (the buffer items were excluded in the recall). All items had different first letters. The first two initial letters were presented and were provided as cues in the recall phases, which the participants then had to remember and complete. Recall performance was defined as the number of correctly recalled items for each recall phase.

Working memory capacity tasks

After some initial practice with the corresponding tasks, participants completed two complex span tasks (operation span and reading span) to assess individual working memory performance. A total memory span score was computed as the overall mean proportion correct responses from the Ospan and the Rspan task (see Schurer et al., 2020, for details). WMC was not analyzed further in this study, but was nevertheless included in the analyses as a control variable.

Content knowledge test

To investigate their general knowledge about the copyright law, participants completed a paper-pencil content knowledge test about general copyright law aspects with a total of five 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.

Hypertext reading

Participants read an expository hypertext about the copyright law (see Schurer et al., 2020, for details). A version with high cohesion (easy condition) and low cohesion (difficult condition) was created. Both versions were identical to Schurer et al. (2020). We used the same cohesion manipulations at the local and global levels as McNamara et al. (1996). There was a total of 68 manipulations. On average, one to two manipulations appeared on a global level and about five on a local level in a text segment of 500 words. The length of the highly cohesive version was 4,870 words and the length of the low cohesive version was 4,620 words. The text differed in length (e.g., by removing headings or connectors), but not in text content. The average Flesch Reading Ease score was 35 in an easy and 38 in a difficult state, indicating a medium level of difficulty (Schöll, 2015). The text was displayed on a computer screen as several pages in black on a white background. One page contained about 500 words. Participants continued to the next page by clicking the "Next" button in the lower right corner of the screen. They could not return to read a page again after clicking on the next page but were given as much time as they needed to read the text. Participants were informed before reading that they had to take a reading comprehension test after the reading process.

Mind-wandering probes

Before participants started reading the hypertext, they were presented with an instruction, which contained a definition of mind wandering, which was used in previous studies (Schurer et al., 2020; Smallwood et al., 2007, p. 533). During reading the hypertext, participants were asked at random intervals of 2–4 min with an average duration of 3 min what they were thinking about immediately before the thought probe appeared. This question appeared in a pop-up window at the bottom of the screen with a beep (Stawarczyk et al., 2011a, b; Unsworth & McMillan, 2013). With the appearance of the thought probe, participants had to select an answer from four answer categories in line with their instructions by pressing the corresponding number on their keyboard. The participants` thoughts could be directed either on: (1) the text; (2) how well I understand the text; (3) the current state of being; (4) a memory in the past or something in the future (Unsworth & McMillan, 2013). After responding to a category, the participants continued reading the text. For this response category the proportion of TUT-responses was computed, with a higher proportion indicating more mind wandering. Furthermore, we did not define the mind-wandering categories as goal-related (TUTs that are used for the maintenance of future task goals) or goal-unrelated (TUTs that are related to personal issues and concerns; see

Rummel et al., 2017; Steindorf & Rummel, 2017). To ensure comparability with our previous study (Schurer et al., 2020), we used category classifications that are based on Smallwood et al.'s (2007) definition and include similar categorizations as those in McVay and Kane (2012b). In addition, we recorded the times for reading the entire hypertext.

Reading comprehension test

To test participants' understanding of the text, they completed a paper pencil reading comprehension task with a total of 12 single-choice questions. Each question contained four possible answers, from which the participants had to choose one. During this task, the participants had no access to the hypertext. The results were the sum of the correctly answered questions.

Memory test

The situational model of the text develops a mental representation of the text content and organizes it in memory (Ericsson & Kintsch, 1995). In the memory test, participants had to distinguish whether a sentence presented on a screen appeared in the hypertext or not. There were 16 sentences in total, eight sentences were original text sentences, and eight sentences were manipulated either on surface or textbase structure. Manipulations on surface structure consisted of the shifting of a clause within the base sentence to a new position, so that the surface sentence structure changed, whereas manipulations on textbase structure consisted of replacing a proposition in the base sentence, so that the meaning of the text altered (see Schurer et al., 2020, for details). For statistical analyses, correct percentage answers were calculated.

Statistical analyses

All statistical analyses were carried out using IBM SPSS Statistics 23.0. An alpha value of .05 was adopted for all significance testing. Estimated effect sizes are reported using partial eta squared (η_p^2). Post hoc tests were adjusted using Bonferroni correction. Analyses of covariance (ANCOVAs), analyses of variance (ANOVAs), and paired t-tests were conducted for the analyses of mind wandering, reading comprehension performances, as well as PM task performance. In a *first* analysis, we examined the potential influence of different factors on mind wandering and conducted a two-way ANCOVA to analyse the interaction of the factors PM task group and text difficulty. WMC was included as a control variable in the analyses, in order to control for potential confounding influences of WMC on the findings (e.g., Schurer et al., 2020). To follow up, significant interaction of task group and text difficulty post hoc t-tests were conducted. In a *second* analysis, we examined potential influencing factors on reading comprehension (text comprehension and text memory) and conducted two-way ANCOVAs to analyse the interaction of the PM task group and text difficulty. In a *third* analysis, we examined PM task performance via a 2 (unfinished, finished) × 2 (recall phase: first, second) mixed-factorial design. As a subsidary analysis, we looked at the correlations between the TUT rates, reading comprehension measures and reading time.

In addition, we used a Bayesian model-selection approach because of the extended possibilities for model testing and model selection compared to the more commonly used null-hypothesis testing approach (see, e.g., Gelman et al., 2013; Kruschke, 2014). Note that the Bayesian approach allows for proper model selection, which is based on an assessement of the strength of evidence associated with the null model or its rejection as the alternative model. In the following sections, Bayes factors are interpreted according to the proposal of Jeffreys (1961), with BF < 3 indicating anecdotal evidence, BF > 3 indicating moderate evidence, BF > 10 indicating strong evidence, and BF > 100 indicating overwhelming evidence for a model assuming or rejecting the null hypothesis (see also Lee & Wagenmakers, 2013). Furthermore, we report the common information for ANCOVAs and t-tests, but use the additionally reported Bayes factors to draw conclusions concerning our hypotheses. To this end, for all our analyses, we included WMC as the only factor in the null model and report BF_{10} as the Bayes factor in favour of the alternative model. Thus, BF_{10} values < 0.3 are strong evidence in favour of the null model.

Results

Two-back task performance

Table 1 presents descriptions of sample characteristics. A series of ANOVAs revealed no significant differences between the experimental PM task groups (finished, unfinished) concerning gender, age, prior knowledge, WMC, and PM task performance in both recall phases (all *ps* > .05). This finding indicates that the participants were comparably engaged in the reading task setting, regardless of the particular PM task condition they received.

First analysis: Mind wandering

Looking at the mean proportion of the unfinished and finished PM task group, participants experienced more TUTs (33.9%) in the unfinished than in the finished PM task group (25.8%). A two-way ANCOVA was run to examine the effect of PM task group, and text difficulty, with WMC as a control variable on overall mind wandering and

Table 2 Mean proportion of mind wandering, comprehension scores, and recall scores for the unfinished and the finished text groups

Measure	All participants $n = 72$	Unfinished group $n = 36$	Finished group $n = 36$
Thought probes			
TRTs	.70 (.15)	.66 (.14)	.74 (.16)
Text	.47 (.22)	.43 (.18)	.51 (.25)
Text-related thoughts	.23 (.15)	.23 (.14)	.23 (.17)
TUTs	.30 (.15)	.34 (.14)	.26 (.16)
Current state of being	.20 (.14)	.26 (.14)	.14 (.13)
Something in the past/future	.10 (.11)	.08 (.09)	.12 (.13)
Comprehension			
RC score	7.25 (1.55)	6.78 (1.53)	7.72 (1.58)
Original sentences (%)	.665 (.191)	.670 (.150)	.660 (.226)
Surf. manipulations (%)	.302 (.214)	.264 (.179)	.340 (.240)
Text. manipulations (%)	.735 (.229)	.763 (.214)	.708 (.242)
False errors (%)	.531 (.173)	.507 (.137)	.556 (.201)
PM task performance			
Recall 1 score	6.03 (1.94)	5.92 (2.09)	6.14 (1.79)
Recall 2 score	4.28 (1.78)	4.15 (1.84)	4.42 (1.73)

TRTs task-related thoughts, *TUTs* task-unrelated thoughts, *RC* reading comprehension, *Surf.* Surface, *Text.* Textbase. Values represent means, SD given in parentheses

mind-wandering categories "current state of being." For the total amount of mind-wandering rates, we found significant main effects for PM task group ($F(1,67) = 5.457$, $p = .022$, $\eta^2 = .075$), and text difficulty ($F(1,67) = 7.971$, $p = .006$, $\eta^2 = .106$), with strong evidence ($BF_{10} = 14.33$) for both effects also in the Bayesian analysis. We could not find any significant interaction (all $ps > .05$). The ANCOVAs conducted on the mind-wandering category "something in the past/future" did not reveal any significant main or interaction effects (all $ps > .05$). Looking at the mind wandering category "current state of being", another ANCOVA found a significant main effect for the PM task group ($F(1,67) = 16.933$, $p = .000$, $\eta^2 = .202$), and text difficulty ($F(1,67) = 16.059$, $p = .000$, $\eta^2 = .193$). Participants in the unfinished group showed significantly more TUTs concerning the current state of being ($M = .259$, $SD = .114$) than the finished group of participants ($M = .140$, $SD = .132$; see Table 2). The significant main effect of the factor text difficulty revealed an increase in TUTs when reading difficult texts ($M = .259$, $SD = .165$) compared to easy texts ($M = .141$, $SD = .107$). As expected, the two-way interaction between PM task group and text difficulty was significant ($F(1,67) = 5.841$, $p = .018$, $\eta^2 = .080$). The results of a Bayesian ANCOVA were consistent with the results of the classical ANCOVA. Further support for a significant interaction comes from a Bayes factor of $BF_{10} = 3.08$.

Further, a paired t-test was run to determine whether there was a difference between mind-wandering rates when participants read the easy text compared to the difficult text between the PM task group.

For the difficult text condition the analysis showed significantly more TUTs for participants in the unfinished ($M = .35$, $SD = .12$) than in the finished group ($M = .16$, $SD = .15$; $t(34) = -5.073$, $p = .000$; see Fig. 1). Additional Bayesian t-tests supported these results with $BF_{10} = 116.61$ for the difficult text condition. In the easy text condition, there was no significant difference between the unfinished ($M = .16$, $SD = .10$) and the finished group ($p > .05$; see Fig. 1), which was paralleled by $BF_{10} = 0.687$. However, this result represents only anecdotal evidence for the null hypothesis.

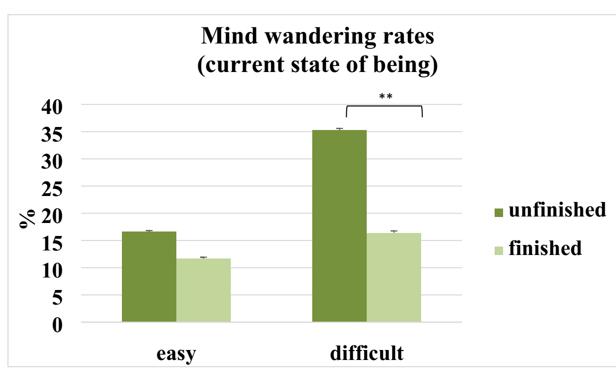

Fig. 1 Proportion of task-unrelated thoughts (current state of being) between the groups for easy and difficult texts

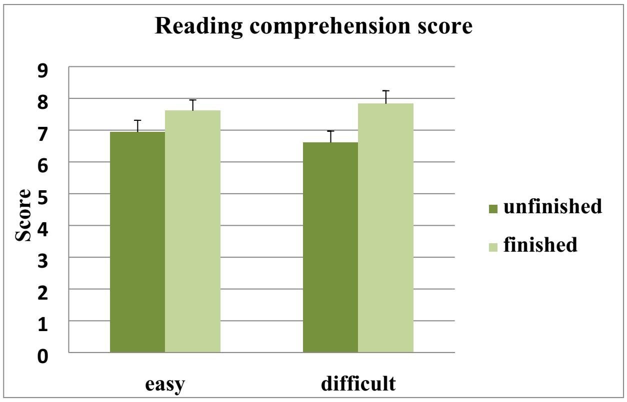

Fig. 2 Mean differences in the reading comprehension score between the groups for easy and difficult texts

Second analysis: Reading comprehension and PM task performance

For the easy text condition, the mean sum of correct answers in the reading comprehension test amounted to $M = 6.94$ ($SD = 1.55$) in the unfinished and to $M = 7.61$ ($SD = 1.46$) in the finished group. For the difficult text condition, the mean sum of correct answers in the reading comprehension test amounted to $M = 6.61$ ($SD = 1.54$) in the unfinished and to $M = 7.83$ ($SD = 1.72$) in the finished group. Using working memory as a covariate, the ANCOVA analysis revealed that there was a significant main effect for the PM task group on reading comprehension ($F(1,67) = 6.409$, $p = .014$, $\eta^2 = .087$; see Fig. 2). Participants in the finished PM task group showed a better reading comprehension score ($M = 7.72$; $SD = 1.58$) than participants in the unfinished PM task group ($M = 6.78$; $SD = 1.53$). We could not find a significant main effect of text difficulty on reading comprehension (all $ps > .05$). The two-way interaction was not significant ($p > .05$). This result makes it clear that despite possible differences in WMC, the effect of the PM task on reading comprehension would remain.

We also assessed memory for the text by the recognition of sentences that were manipulated on the surface or at text base level. Participants in the unfinished PM task group correctly recognized more textbase manipulations (76%) than participants in the finished PM task group (71%). A two-way ANCOVA was run to examine the effect of PM task group, and text difficulty with WMC as a control variable on correctly recognized sentences. The ANCOVA conducted on correctly recognized surface manipulations did not reveal any significant main effects or interaction (all $ps > 0.05$). The ANCOVA conducted on correctly recognized textbase manipulations did not reveal a significant main effect of PM task group, or text difficulty (all $ps > .05$). In addition, no significant interaction between PM task and text difficulty was revealed ($p > .05$) (see Fig. 2). The memory performance was not affected by the presence versus absence of a second task still in mind.

Further analysis As an additional result and in order to assess the relationship between the amount of mind wandering and reading performance, we conducted Pearson's correlation analysis between the related values. We did not observe a significant correlation between mind-wandering rates and reading comprehension score (all $ps > .05$), except for a low significant negative correlation between the mind-wandering category "something in the past/future" and correctly recognized original sentences ($r = -.255$; $p = .031$). However, the analysis indicated a low significant positive correlation between overall reading times and reading comprehension score ($r = .238$, $p = .044$), which indicates that participants performed better on the reading comprehension test if they read longer. The Bayesian factors for the models were $BF_{10} = 1.74$ when correlating TUTs about the past/future with correctly recognized original sentences and $BF_{10} = 1.28$ for the correlation of reading time with reading comprehension score. Thus, the evidence was not very strong but anecdotal (Lee & Wagenmakers, 2013). Nevertheless, this relationship could explain the lack of correlations between mind wandering (current state of being) and reading comprehension. However, due to the weak evidence, these results should be interpreted with caution.

Further, we investigated differences between participants in the recall performance**.** A 2 × 2 ANOVA with PM task group (unfinished vs. finished) as between-participants' and recall phase (first, second) as within-participants' factor showed that participants performed better in the first ($M = 6.03$, $SD = 1.94$) than in the second recall phase ($M = 4.28$, $SD = 1.78$; $F(1,70) = 77.156$, $p = .000$, $\eta^2 = .524$). We could not find a significant main effect for PM task group on performance ($F(1,70) = .382$, $p = .539$, $\eta^2 = .005$) and no significant interaction between PM task group and recall phase on performance ($F(1,70) = .011$, $p = .917$, $\eta^2 = .000$).

Discussion

The present study aimed to examine whether mind wandering can be induced by an additional demand and how this induction is modulated by text difficulty in a complex reading situation. In addition, the study aimed to test different models of mind wandering against each other with the use of an additional demand. Therefore, we chose a PM task in a reading task setting, which differed in text difficulty. This should show that participants having a second task in mind experience more TUTs than participants who think a second task is finished when reading difficult texts. We found that participants in the unfinished group experienced more TUTs (overall TUTs and category "current state of being") than participants in the finished group when reading difficult but not easy texts. Although we found significant effects on mind wandering, we could only find a significant main effect of the PM task on reading comprehension, but no significant interactions on reading comprehension. A further analysis showed that participants probably compensate the influence of the second task by reading longer, which in turn has a positive effect on their reading comprehension performance.

Mind wandering

We hypothesized that mind wandering would be influenced by an interaction of two factors: text difficuty (easy vs. difficult) × PM task group (finished vs. unfinished). We found a greater difference in mind wandering between the finished and the unfinished group when reading the difficult text compared to the easy text, with more mind wandering occurring in the difficult text version. Thus, these results demonstrated that the frequency of mind wandering (thoughts about the current concerns) can be influenced by increasing task demands when reading difficult texts, which needs to be discussed in the light of previous studies on mind wandering and PM task situations.

The current findings are related to results of the study of Steindorf and Rummel (2017), in which participants in the unfinished group and the finished group did not differ in the general amount of off-task processing during an ongoing task. However, the results showed a change in the content of off-task processing with larger amount of thoughts goal-related to the fulfillment of PM task requirements in subjects of the unfinished task condition.

On the basis of these findings and of a further study (Rummel et al., 2017) the authors argued that under high task demands, i.e., when all resources are committed, less mind wandering might also occur but that the content of the off-task thoughts might even be more focussed on the primary task processing (see also Rummel et al., 2017). This view would predict that in the current study participants in the unfinished group should not show more TUTs than participants in the finished group when both groups are already engaging in a demanding reading of a difficult text. Neither predictions are consistent with the present results. Nevertheless, this discrepancy can be explained by differences in the overall task requirements between the studies of Rummel et al. (2017) and the current study.

In more detail, we used a far more complex reading task than the ongoing primary tasks in the studies of Steindorf and Rummel (2017), i.e., an N-back task, and of Rummel et al. (2017), i.e., a lexical decision task, which, probably, left sufficient space for subjects' mental resources to cope with the requirements of the ongoing task. Therefore, the fact that we used a much more demanding task than Steindorf and Rummel (2017) would suggest that the degree of complexity of the primary ongoing task should be considered as an important factor when determining the factors potentially affecting the occurrence of TUTs (and of their content) in finished and unfinished task conditions. In the present study, we found an influence of the PM requirements on the occurrence of mind wandering in the difficult reading condition but not in the easy reading condition. This is consistent with the assumption that the mental resources in the easy reading condition might have already exhausted mental resources to a degree that allowed just for proper task fulfilment of the ongoing task together with a sufficient control of off-task processing in the PM task. This would also be consistent with the findings of Konu et al. (2021), who demonstrated that the emergence of thoughts can vary depending on task complexity.

This explanation would also relate to the findings by Smallwood and Schooler (2006); see also Smallwood & Andrews-Hanna, 2013), who demonstrated more mind wandering when tasks were easy, so that more executive resources remained available for mind wandering. On the other hand, when task demands were high, fewer resources were available and less mind wandering occurred. Interestingly, the drop in mind wandering with increasing task difficulty has been argued to be steeper for people with higher WMC (Smallwood & Andrews-Hanna, 2013). Our results are rather opposite to this view: Mind wandering increased in the most difficult condition (difficult text and PM demands), while it was lowest in the easy condition with the finished PM task and an easy text. Nevertheless, this latter observation would be consistent with the assumption that the difficulty of the general task situation, differing accross studies, affects the degree of participants' involvement in task processing and consequently the occurrence of mind wandering. Neither of the above views fully explains the interaction between cognitive resources and task demands as observed in the present study, although each model would partially be consistent with parts of our results. Instead, the overall pattern of findings is suggestive for a rather complex interaction of the demands related to the main task, the task aimed at inducing TUTs and also the individual resources of subjects allowing more or less task involvement, which is consistent with the present *resource-demand-matching view*.

In more detail, given that WMC did not differ between groups in our study (see Table 1), a matching of resources takes place in the easy and difficult text condition. The additional PM task adds an additional demand, which then leads to a breakdown of the existing cognitive resources and therefore to a mismatch in the difficult text condition due to the assumption of our model. Therefore, the results show more mind wandering in the difficult condition with an unfinished task in the mind. Furthermore, it seems that the combination of two demanding tasks, i.e., reading a difficult text while memorising items from a to-do-list, was sufficient to create additional demands, which far exceed the resources. When task demands are high, executive control capabilities are decreased and fewer resources are available to perform a primary task (McVay & Kane, 2010). On the other hand, unfulfilled tasks and goals in mind represent additional cognitive demands. For this reason, the interaction of higher demands and unfulfilled tasks in the mind leads to mind wandering. In future studies, more integration should occur across theories to indicate the complexity of TUTs. Our model aims to contribute to this by looking at the interaction of demands and resources. Notably, issues of power also need to be considered when discussing the pattern of PM-related findings observed by different studies, which will be accomplished later below.

Interestingly, our results were significant only with respect to the mind-wandering category "current state of being". A potential explanation might be offered by the personal relevance of the PM task, which encompassed a to-do list of students' daily activities. It is conceivable that a self-relevant PM task could tap similar resources to self-relevant worries, thereby inducing mind wandering (see also McVay & Kane, 2013).

Reading comprehension and recall performances

We further hypothesized that participants reading a difficult text with a second task in mind (unfinished group), would show less text comprehension results compared to participants reading an easy text version. Participants who did not remember a second task (finished group) showed significantly better results in the reading comprehension test than participants with a second task in mind (unfinished group). The control for potential differences in working memory capacity by the ANCOVA results showed little or a negligible impact of WMC on the comprehension scores. This indicates that working memory does not account for a significant amount of variance in the current study. We further tested the impact of the PM task group (unfinished, finished) and recall phases (first, second) on recall performance. The observation of a significant main effect of recall phases on PM task performance indicates that the PM task manipiulation was effective. We found further that the participants performed worse in the second recall phase than in the first recall phase. In contrast, PM task performance decreased over time in both groups (unfinished, finised). In the first recall phase, the performance was identical between the two groups (unfinished, finished) as expected, and the observed significant effect of PM task groups on TUTs was therefore not caused by a potential memory difference between groups. Contrary to the study of Steindorf and Rummel (2017), the performance of the reading task was affected by the PM task group (unfinished and finished group). It seems that the second task distracts participants when reading attentively, even if no significant correlation between reading comprehension and TUTs can be found. While in the study by Steindorf and Rummel (2017) the PM task manipulation (unfinished, finished) had an influence on the performance in the second recall phase, we found an influence on the performance in the primary task (reading comprehension test). One reason for this result could be that we used a more complex primary task in contrast to the n-back task. This suggests that the relationship between the different demands of the primary and the secondary tasks (text difficulty, PM task) plays an important role. Due to the more demanding reading task, the forgetting rate in the second recall phase seems to be the same in both groups (unfinished, finished). In the study of Steindorf and Rummel (2017), however, the participants of the unfinished group still remembered the items of the second recall.

Contrary to our expectations, we did not observe a negative association between comprehension measures and the frequeny of mind wandering. In the present study, an increased amount of mind wandering did not reduce text comprehension. An additional test revealed a significant negative correlation between the mind-wandering category "something in the past/future" on correctly recognized original sentences. This could be an indication that the participants think more about the second task, i.e., the additional demand, which in turn might affect the more surface text comprehension, and thus the results here are to be interpreted with caution due to the lack of moderate-sized correlations (r = .030; Cohen, 1992). Moreover, the present experimental study was not designed to rigorously investigate correlational patterns, and therefore the related findings in the current study do not represent the main vein of our argumentation. Nevertheless, a potential explanation could be that mind wandering can be compensated by longer reading times, which retains task performance (in terms of reading comprehension), but is still less efficiant because more time is needed for the same performance level. In fact, the current findings showed a positive correlation of reading time with reading comprehension, which might have meant that a prolongation of the the reading time led to better understanding of the text and, thus, possibly could compensate for the influence of the PM task, as the significant main effect of the PM task group on reading comprehension might indicate (participants showed a better reading comprehension score in the finished than in the unfinished condition). This could be evidence that participants were less successful in construction situation models when reading these texts, which might lead to more mind wandering, and which does indeed reduce text understanding. However, due to the low correlation, this result should be interpreted with caution. Noteworthy, we observed a similar correlation in a previous study by our group (see Schurer et al., 2020) and, therefore, consider reading time as a mediator, which needs to be investigated in more detail in future studies. Furthermore, our findings require further replication in larger samples. Likewise, this supports the assumption that the reading task, unlike the primary task of Steindorf and Rummel (2017), was so demanding that the participants in the unfinished group had no chance to remember better. However, reading time was not associated with any variation in mind wandering. The precise role of such compensatory processes remains to be elucidated in future studies. Another explanation could be that few studies of mind wandering included expository texts. For example, Kane and McVay (2012) found a positive relationship between mind-wandering measures and narrative text comprehension, but this was not found for expository text comprehension. More studies investigating mind wandering and expository text comprehension would be needed to find out if findings from studies of mind wandering in narrative text comprehension could be transfered to expository texts. Former studies showed that the frequency of mind wandering and its influence on text comprehension is strongly associated with topic interest and motivation to do well in the task (Unsworth & McMillan, 2013). A limitation of our study is that we did not control interest and motivation.

Limitations

Finally, it has been argued that studies, despite an achieved power of 80%, sometimes have insufficient sample sizes to ensure scientific conclusions that meet the requirements of strong and optimal power considerations (Brysbaert, 2019). Such power issues should be discussed with respect to the current findings and, in particular, to the seemingly diverging pattern of findings about the potential impact of PM manipulations on the occurrence of mind wandering as mentioned before. In calculating the sample size for the current study, we assumed a rather large effect size based on the calculation of the effect sizes in selected but comparable studies (see Footnote 1). Undoubtedly, an increase in subject numbers would have been desirable in order to ensure valid detection of significant findings under conditions of smaller expected effect sizes, just as the application of a Bayesian approach would do if this approach was applied in order come to an evidence-based assessement of the rejection or acceptance of the null hypothesis (see Brysbaert, 2019). Therefore, the current findings need to be considered with caution and need to be carefully compared with the overall pattern of related studies. Based on our own findings, a power of .82 is expected when calculating an ANCOVA (see G*Power, Faul et al., 2007), which is comparable to the expected power in other studies applying similar designs of inducing mind wandering with unfinished versus finished PM task-related manipulations. For example, the calculated power in the cited studies ranges from .52 to .90 (Masicampo & Baumeister, 2011; Rummel et al., 2017; Scullin et al., 2018; Steindorf & Rummel, 2017). In more detail, a power of values between .63 and .95 was expected in the study by Rummel et al. (2017, Experiments 1–3), a power of .67 in the study by Steindorf and Rummel (2017), and a power of .80 in Scullin et al. (2018, Experiment 2). While this pattern of power values would suggest considerable validity of the observed findings when speaking about the isolated studies, an overall conclusion based on a summarized view across several studies just at the cutoff for sufficient power might suffer from the the occurrence of effects just reaching significance by incidence. As had been noted, this is an issue for many studies in cognitive psychology and often relates, in particular, to studies with more complex experimentals designs investigating the effects of several factors and their interaction on cognition (see also Brysbaert, 2019). For the current experimental design combining a two-factorial design with a factor on participants' individual WM performance, a sample size of $N = 210$ participants would be required on the basis of an a priori sample size calculation with G*Power assuming an expected power of 95% and a medium effect size of $f = .25$ (and of 1,302 participants when assuming a small effect size; Brysbaert, 2019). While complex factorial designs seem necessary to investigate the current research question, the recruitment of large sample-sized studies might be challenging for future studies. Therefore, further studies with larger sample sizes are definitely needed to validate the conclusions of the current study together with alternative approaches to ensure sufficient validity of the perceived conclusions, such as the conduction of independent replication studies (LeBel et al., 2017) and obtaining converging evidence with related designs or coming from other methodological perspectives. This would allow for broader methodological approaches when evaluating the validity of the proposed model to explain the effects of task difficulty, cognitive resources and task requirements on the distraction of attention from task processing (Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011b; see also LeBel et al., 2017).

Conclusion

The present study gives insights into attention processes when reading digital texts. Moreover, the present study showed what happens if mind wandering was induced by a second task in mind when task demands were high. Furthermore, the study provided partial support for the *resource-demand-matching view* of mind wandering, although the model needs to be examined more closely in future studies. The interaction between text difficulty and PM task group had an impact on mind wandering. Participants who read the difficult text can only absorb the additional demands without a second task still in mind. Based on these results, it is important to think about the task itself, since too-easy tasks can lead to falsifying the results. Therefore, it is essential to match the task requirements to the available resources. The *resource-demand-matching view* could be further investigated by further studies in other contexts, for example during online reading, and here in particular, during reading of hypertexts. In particular, the deliberate distraction of the reading process, for example by pop-up windows or messenger messages that pop up when reading could be of interest for the model mentioned above (e.g., Levy et al., 2016).

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Availability data All datasets generated for this study are included in the article.

Code availability Not applicable.

Author's contribution Teresa Schurer: conceptualization, methodology, data curation, formal analysis, visualization, writing – original draft. Bertram Opitz: conceptualization, methodology, data curation, writing – review and editing. Torsten Schubert: conceptualization, methodology, writing – review and editing.

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Declarations

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.

Ethics statement/Consent to participate The study was approved by the ethics committee of the Deutsche Gesellschaft für Psychologie (DGPs). The experimental protocol conformed to tenets of the Declaration of Helsinki and written informed consent was obtained from each participant before the commencement of the study.

Consent for publication Not applicable.

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