Consciousness and Cognition 134 (2025) 103918

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/yccog

Full Length Article

Do eye movements reflect readers' thoughts during reading? Evidence from multidimensional experience sampling and eye movements

Diane Mézière[a,*], Johanna K. Kaakinen[a,b], Emilia Ranta[a], Karin Kukkonen[c], Jonathan Smallwood[d], Jaana Simola[e]

[a] Department of Psychology and Speech-Language Pathology, University of Turku, Finland
[b] INVEST Research Flagship and Research Center, University of Turku, Finland
[c] Department of Literature, Area Studies and European Languages, University of Oslo, Norway
[d] Department of Psychology, Queen's University, Kingston, Ontario, Canada
[e] Department of Education, University of Helsinki, Finland

ARTICLE INFO

Keywords:
Immersion
Reading
Eye movements
Mind-wandering

ABSTRACT

While reading narrative texts, readers' attention often fluctuates from the text (e.g., immersion) to text-unrelated thoughts (e.g., mind-wandering). Research on mind-wandering and immersion suggests that they influence the reading process differently. In this article, we examine the types of thoughts readers have while reading a literary text. Specifically, we investigated the effect of immersion and mind-wandering on eye-movement behaviour during reading. Fifty-six participants read extracts from a novel while their eye-movements were monitored. Participants' thoughts were probed using multidimensional experience sampling. We identified four types of thought: Immersion, Mind-wandering, Sub-Vocalization, and Social Episodic Thoughts. We then ran General Additive Mixed Models (GAMMs) to examine the relationship between these thought types and eye movements. Results show that eye movements are influenced by the types of thoughts readers experience while reading literary texts. These results have important implications for the way that mind-wandering is typically investigated, particularly in reading research.

1. Introduction

Literary narratives induce a variety of different kinds of thoughts in the reader. A good literary text may transport the reader to the narrative world (Gerrig, 1993; Green & Brock, 2000), which entails absorbing the reader's attention to the content of the narrative, inducing detailed mental imagery of the characters and the narrative world around them, and raising emotions, like suspense and eagerness to know how the story ends (Appel et al., 2015). On the other hand, the reader's thoughts might easily diverge from the literary story to unrelated issues, like what to eat for dinner, or events that happened yesterday. Experiences when our mind wanders away from the text to personal concerns are common, as mind-wandering episodes have been reported to occur between 30 % and 49 % of the time during reading (Bixler & D'Mello, 2016) to 49 % (Uzzaman & Joordens, 2011). Often work studying mind-wandering uses relatively dry uninteresting texts and studies have found that this type of attentional disengagement varies with how interesting

* Corresponding author at: Assistentinkatu 7, University of Turku, 20014 Turku, Finland.
E-mail address: diane.meziere@utu.fi (D. Mézière).

https://doi.org/10.1016/j.concog.2025.103918
Received 3 February 2025; Received in revised form 25 July 2025; Accepted 30 July 2025
Available online 5 August 2025

the text that is being read is (Smallwood et al., 2009).

The purpose of the present study, therefore, was to understand the different kinds of thoughts that emerge when reading a literary novel, and to understand how these thought patterns are reflected in the readers' eye movements during reading. By studying an engaging literary text we expected that two types of thoughts would emerge during reading: experiences of immersion, which should be characterized by focused attention on the text and vivid imagery; and experiences of mind-wandering, characterized by off-task thoughts whose content was unrelated to the narrative. In this way by studying a engaging text we hoped to better characterize the state of immersion in what we are reading which has been considered an important factor in literary reading experience (Gerrig, 1993; Kuijpers et al., 2014; Ryan, 2001) as well as states of mind-wandering that reflect disengagement from what is being read (see Smallwood, 2011; Szpunar, 2017) and is associated with poorer comprehension and memory of the text (Smallwood et al., 2008; Bonifacci et al., 2023; D'Mello & Mills, 2021). Fabry and Kukkonen (2019) challenged this view and suggested that mind-wandering can also have a role in making sense of a narrative, as it may allow the reader to reflect on the information presented in the text in the light of their own experiences and knowledge. By examining what kind of thought patterns emerge during literary text reading and how they are reflected in the readers' eye movement records we will provide novel information on how the shifts of attention between the text and self-generated thoughts are reflected in reading processes (Smallwood, 2011).

1.1. Immersion to the story world

When immersed or transported to the story world, a reader's attentional capacity is fully focused on the text, and the text induces imagery and emotions in the reader (Gerrig, 1993; Green & Brock, 2000; Kuijpers et al., 2014; Ryan, 2001). The reader may experience vivid images of the narrative characters and events, and react spontaneously to narrative events, such as hoping that a character would be saved from a dangerous situation or considering how an unpleasant turn of events how it could have been avoided. Immersion may thus entail different types of thoughts from detailed and vivid imagery to empathy felt towards the characters. What is common to these thoughts is that they are all triggered by the text and related to the story world described in it, and that they are characterized by focused attention on the reading task.

Previous studies provide empirical support for the idea that immersion is characterized by increased attention on the narrative stimuli. In a study by Bezdek and Gerrig (2017), participants were slower to respond to unrelated sound probes during viewing of a movie if they reported high immersion, indicating that their attention was more absorbed to the film. In a study on listening of literary narratives, Kaakinen and Simola (2020) observed that higher immersion to a story was related to fewer eye blinks during the listening task, indicating increased or more focused attention to the text.

Jacobs (2015) suggested that during reading immersion to the story world should increase reading fluency or efficiency, reflected in eye movement behavior as longer saccades and shorter fixations. According to Jacobs, emotion-inducing text segments are more likely to increase immersion, and consequently, emotional and especially suspense-inducing text segments should be read with longer saccades and shorter fixations. While there is empirical evidence showing that emotional texts tend to induce more immersion than neutral texts (e.g., Ballenghein et al., 2023; Kaakinen & Simola, 2020), very few empirical studies have directly tested how immersion is reflected in eye movement behavior during reading (Eekhof et al., 2021; Lei et al., 2023). Eekhof et al. (2021) used eye tracking to examine whether immersion in the story world was reflected in the sensitivity to word characteristics such as word length and frequency during reading. Some of the most robust findings in reading research is that longer and less frequent words attract longer fixations than shorter and more frequent words (for review, see Rayner, 1998). Eekhof et al. were interested in whether the magnitude of these effects is associated with subjective experiences of immersion. They found that higher immersion was related to a smaller word length effect on gaze duration, an early eye movement measure associated with early processes in reading (e.g., lexical access). This finding suggests that reading is less affected by orthographic features of the text during immersion, supporting the idea that immersion is associated with higher reading efficiency (Jacobs, 2015).

In another recent study, Lei et al. (2023) examined how immersion is reflected in eye fixation times on words that have the potential to elicit negative or positive emotions. Previous eye tracking research has demonstrated that emotional words (either positive or negative) embedded in sentences are read with shorter gaze durations than neutral words (Knickerbocker et al., 2015; Scott et al., 2012; Sheikh & Titone, 2013; 2016; Yan & Sommer, 2015; 2019). Lei at al. found that higher immersion was related to increased gaze duration on positive words, whereas there was no evidence for an effect of transportation for negative or neutral words. This finding implies that the effect of immersion on early reading processes may depend on the valence of the text content: immersion may slow-down the reading of words within text segments that induce positive emotion.

In summary, there still is very little empirical evidence on how immersive experiences are reflected in eye movements during reading but the few studies show that the effects may depend on the text characteristics: while high immersion may be related to less sensitivity to word length and thus, manifest as shorter fixation durations and faster reading (Eekhof et al., 2021), it may also be related to higher sensitivity to the positive emotional content of the text and result in longer fixation durations and slower reading (Lei et al., 2023).

1.2. Mind-Wandering during reading

Mind-wandering has been used to refer to a variety of thought patterns that may arise in different contexts. Many studies have defined mind-wandering as instances of task-unrelated thought, whereas others have defined it as having stimulus-independent thought, or as stimulus-independent and task-unrelated thought (see Seli et al., 2018). These types of thought patterns are hypothesized to be opposite to immersion, which can be defined as a type of stimulus-dependent thought. Some definitions of mind-wandering have emphasized that it entails unintentional or off-task thought (see Seli et al., 2018). Seli et al. (2018) suggested that instead of settling on a single definition for mind-wandering, it would be more fruitful to acknowledge that mind-wandering is a heterogeneous concept and define the specific experiential features that are of interest to the current investigation.

As for mind-wandering during reading, Smallwood (2011) defined off task mind-wandering as being characterized by a state of decoupled processing of the text that allows the reader to peruse internal thoughts that are unrelated to the narrative. According to this view, the shift of attention from the text stimuli to reader-generated internal thoughts results in reduced perceptual processing of the text, which is then reflected in poorer comprehension of the text information (Smallwood, 2011). If the text is not properly processed at earlier stages (e.g., lexical access), the text information is not integrated to the mental representation of the text, explaining why off task thought can impair individuals from drawing inferences regarding events in the text (Smallwood et al., 2008). In this way the emergence of a perceptually decoupled state when reading would impair the emergence of states of narrative driven emergence.

Many previous eye tracking studies on mind-wandering during reading have focused on this kind of "zoning out" or mindless reading, with conflicting results. Some studies suggest that mind-wandering episodes are associated with slower reading times, such as longer fixation durations, which have been observed both in early measures associated with early processes in reading (e.g., lexical access) and later measures associated with higher-level processes (e.g., integration; Bixler & D'Mello, 2016; Foulsham et al., 2013; Reichle et al., 2010; Steindorf & Rummel, 2020). On the other hand, some studies found no difference in reading or fixation times between mind-wandering episodes and on-task reading (Smilek et al., 2010; Zhang et al., 2020). Similarly, while some studies found mind-wandering to be associated with making fewer fixations or higher skipping rates compared to normal reading (Bixler & D'Mello, 2016; Faber et al., 2018, 2020; Frank et al., 2015; Oyarzo et al., 2022; Smilek et al., 2010; Uzzaman & Joordens, 2011), other studies show the opposite effect, with mind-wandering leading to making more fixations than normal reading (Foulsham et al., 2013; Steindorf & Rummel, 2020).

Eye movement research on mind-wandering during reading has also examined the possible effects of mind-wandering on cognitive processes that support reading by manipulating linguistic variables in the text. Studies investigating the word frequency effect during mind-wandering episodes as opposed to on-task reading suggests that the size of the frequency effect is significantly reduced during mind-wandering compared to on-task reading, particularly on early measures (e.g., gaze duration: Reichle et al., 2010; Foulsham et al., 2013) suggesting that lexical access is influenced by mind-wandering episodes during reading.

Hence, while there is some evidence showing that mind-wandering episodes are associated with differences in eye-movement behavior compared to normal reading, the influence of mind-wandering on eye movements during reading remains unclear. As noted earlier, one possible explanation for such conflicting findings may be that there is more than one type of mind-wandering (e.g., Seli et al., 2018), which in turn may influence eye-movement behavior in different ways. For example, in addition to "zoning out", mind-wandering during reading could entail also reflecting on the text considering one's prior knowledge and experiences (Fabry & Kukkonen, 2019). This type of mind-wandering has been largely ignored in previous reporting of the eye movement results. For example, Smilek et al. (2010) grouped task-related and task-unrelated mind-wandering together in their analyses. Also Steindorf and Rummel (2020) originally probed their participants to indicate if they were thinking about things related to the text they were reading but this response category was left out from the analyses. A more detailed examination of the types of thoughts and mind-wandering episodes that emerge during reading would provide valuable information about the shifts of attention between external stimuli and reader-internal thoughts and their impact on reading processes.

1.3. Aims and research questions

In this study, we aimed to identify the types of thoughts readers have while reading literary texts and describe the relationship between these thoughts and eye-movement behavior. Specifically, we aimed to answer three research questions: 1) What types of thought patterns do readers demonstrate while reading literary texts?, 2) Does the valence of the text (positive, neutral, negative) influence the type of thoughts readers have?, and 3) Is eye-movement behavior during reading influenced by the types of thoughts readers have during reading?

To answer these questions, we leveraged an emerging approach in which experience sampling is used to map multiple features of experience while participants perform different tasks or activities in the lab or in daily life. This approach, known as multidimensional experience sampling (mDES; Smallwood et al., 2016), provides an opportunity for participants to describe the features of their experience on a number of dimensions (e.g. level of detail, relevance to the task) and the resulting data can be decomposed using principal components analysis (PCA) to reveal the dimension that best describe the variance in the reports that participants provide. This approach is important in the current study because it is able to describe patterns of thought that are task-irrelevant (e.g. Turnbull et al., 2019a) but also those that reflect engagement with the task at hand. For example, Wallace et al., (2024) established that mDES can capture patterns of thought during movie watching that relate to engagement with the sensory features of the movie, patterns of episodic thought that support better comprehension of the movie and patterns of distracting intrusive thoughts that impair comprehension. Furthermore, mDES has been shown to be sensitive to indirect measures of cognition, for example, showing robust links to variations in brain activity as identified by functional magnetic resonance imaging (Turnbull et al., 2019a, Konu et al., 2020, Wallace et al., 2024) and electroencephalogram (Simola et al., 2023). This capacity for mDES to provide description of the features of thought patterns with both beneficial and detrimental consequences for engagement with a narrative, combined with its well-established utility as a tool for mapping experiential patterns onto indirect measures of cognition, make it the ideal technique for simultaneously mapping narrative relevant experiential features such as immersion, as well as task irrelevant experiential states such as mind-wandering onto reading behaviour as defined via eye-tracking. The mDES scale used in this study comprised 13 questions regarding the contents of the reader's current thoughts, such as task focus, emotionality, visual imagery, and future vs. past orientation. The responses to the mDES scale were used to identify thought patterns that emerged during reading of a literary text, namely parts of a novel entitled "Memories of the Future" authored by Siri Hustvedt (2019). We then examined whether segments of the novel containing emotionally positive, negative or neutral content induced different types of thoughts in readers. Lastly, we examined the possible influence of these thought patterns on eye-movement behavior during reading.

2. Method

2.1. Participants

Seventy adults, who mostly were university students, participated in the study. Data of nine participants were excluded due to participant not completing the whole experiment, interruptions during testing, or participant reporting that they only skimmed through the text without reading it. Data of five more participants had to be dropped due to poor calibration of the eye tracker. The final sample consisted of 56 participants (51 women, 52 right-handed), whose mean age was 23.43 years (SD = 4.40). All participants were native speakers of Finnish and had normal or corrected-to-normal vision. The study was approved by the Ethics Committee for Human Sciences at the [redacted for anonymity].

2.2. Text materials

The text materials consisted of excerpts from Siri Hustvedt's novel *Memories of the Future* (Hustvedt, 2019), which has been translated to Finnish by Kristiina Rikman. We picked a total of 135 paragraphs from novel's chapters 1, 3 and 4. To keep the flow of the story while making sure that the reading task could be completed within two hours, some text parts were removed, and some originally very short paragraphs were combined.

To select target paragraphs for presenting the thought probes, the emotionality of the paragraphs was rated by 19 participants (14 women, 1 other) who did not participate in the actual experiment. In the rating task, participants read the text one paragraph at a time and evaluated how the text made them feel using the nine-point valence and arousal scales of the self-assessment manikin (SAM; Bradley & Lang, 1994). Six participants could not finish the rating task within two hours, and the final rating data consisted of responses of 13 participants.

Based on the means and standard deviations of the valence and arousal ratings we selected 30 target paragraphs: 10 neutral, 10 positive, and 10 negative paragraphs. The target paragraphs were selected so that these were evenly distributed across the text, and there were never two target paragraphs in a row. The means and standard deviations of the valence and arousal ratings for the target paragraphs, and their mean length are presented in Table 1. Word frequencies for the text were retrieved from pb_sane corpus (Ginter & Laippala, 2017). Thirty simple yes/no questions about the text content, which were presented after each target paragraph, were created to make sure participants were reading the text.

The valence ratings for the positive, negative, and neutral texts were significantly different from each other ($F(2) = 125.8$, $p < 0.001$), and all contrasts were significant (all ps < 0.001). The arousal ratings were also significantly different across text types ($F(2) = 6.54$, $p = 0.005$). Pairwise contrasts showed that arousal was higher for negative compared to neutral ($p = 0.009$) and positive texts ($p = 0.014$), although positive and neutral texts did not differ from each other ($p = 0.978$).

2.3. Multidimensional experience sampling questionnaire

The 13-item Multidimensional Experience Sampling (mDES) questionnaire (Turnbull et al., 2019a) was used to measure the contents of thoughts after each target paragraph. After the first item ("My thoughts and attention were on the task I was performing.") the rest of the items were presented in random order. Participants responded to the items on a scale from 1 to 4 (1 = not at all, 4 = completely; except for emotion item 1 = negative, 4 = positive; and spontaneity item 1 = spontaneous, 4 = deliberate). The items were presented on a computer screen one at a time, with response options presented above the item, and participants responded using the number keys on a keyboard.

2.4. Transportation and reading experience

Transportation to the story world was measured with the short version of the transportation scale (TS-SF; Appel et al., 2015). The scale contained five items, and participants responded to them on a scale from 1 to 7 (1 = not at all, 7 = very much). A sum score of the

Table 1
Means and standard deviations of the valence and arousal ratings and the length of the positive, neutral, and negative target paragraphs.

	Valence		Arousal		Words		Sentences	
	M	SD	M	SD	M	SD	M	SD
Positive	6.21	0.21	2.89	0.67	84.90	40.24	5.20	3.68
Neutral	5.00	0.18	2.85	0.18	89.70	33.77	5.50	2.51
Negative	3.74	0.54	3.50	0.37	98.50	24.74	8.20	5.96
All	4.98	1.08	3.08	0.53	91.03	32.85	6.30	4.36

responses was calculated as Cronbach's alpha (0.76) was reasonably high.

Reading experience was measured with a question "How pleasant or unpleasant this reading experience was?" Participants responded using the nine-point version (1 = extremely unpleasant, 9 = very pleasant) of the self-assessment manikin (SAM; Bradley & Lang, 1994).

2.5. Equipment

The text was presented on a 21″ computer screen with 1920 x 1080 resolution and 144 Hz refresh rate, using 15-point Lucida-Console and triple line spacing. Participants' eye movements were recorded monocularly with Eyelink 1000 system (SR Research Ltd.) at 1000 Hz sampling rate.

2.6. Procedure

Upon entering the laboratory, participants signed an informed consent form. Participants were informed that they would be reading excerpts from a novel, and they were instructed to read the text at their own pace as they would be reading a novel in their leisure time. They were then familiarized with the mDES scale until they said they understood what each item meant. They were told that they would be responding to the mDES scale and a simple comprehension question at random intervals during reading. The eye tracker was then calibrated using a nine-point calibration scheme, and participants completed a short practice trial.

Each page of text was preceded by a drift check, in which a calibration target appeared in the left corner of the screen in the location where the first word of the paragraph would be presented. Participants could proceed to the text by pressing the space bar on a keyboard. After reading the paragraph, participants could proceed to the next paragraph by pressing again on the space bar. After a target paragraph, the first question of the mDES scale appeared in the middle of the screen, followed by the 12 other questions presented in random order. After the mDES scale, participants responded to the comprehension question requiring a yes / no response. The mDES was only presented after target paragraphs. After the comprehension question participants continued reading the text. The experimenter monitored the quality of the eye tracking data, and the tracker was recalibrated if necessary during the experiment.

The text was read in two parts with a short break between the parts. In the end of the experiment, participants responded to the transportation scale and questions on reading experience, their reading habits, and familiarity with the novel. Finally, participants were debriefed about the purpose of the study. The experimental session lasted about two hours.

2.7. Data pre-processing and analysis

All analyses were run in R (R core Team, 2022). The dataset and analyses code are available at: https://osf.io/kd8xa/. First, we conducted a *principal component analysis* (PCA) on participants' responses to the mDES scale to identify the types of thoughts participants were having while reading the text (1997 observations per item). The PCA component scores were then used in the statistical analyses. The PCA was carried out with the trial level responses to the questions on the mDES using varimax rotation, which is the standard method used in previous research (e.g., Konishi et al., 2015; Simola et al., 2023; Sormaz et al., 2018; Turnbull et al., 2019a, b). The PCA was conducted with the 'psych' package (Revelle, 2021). To choose the appropriate rotation method we first ran the PCA using oblimin rotation and looked at the component correlation matrix to check that they did not exceed 0.32 which would indicate an overlap in explained variance between factors (Tabachnick et al., 2007). The correlation matrix is shown in Table 2. As the highest correlation was 0.147, we used varimax rotation, which is in line with previous research using PCA on mDES responses (Simola et al., 2023; Sormaz et al., 2018; Turnbull et al., 2019a, b). We decided on the number of components by running a parallel analysis, using the criterion of retaining components with eigen values > 1 (Simola et al., 2023). Based on this, we selected four components, which is consistent with previous research (Simola et al., 2023; Sormaz et al., 2018; Turnbull et al., 2019a,b). To examine the reliability of these components, we randomly split the data in half and ran the PCA on each split half again. We then compared the component scores from these split-halves datasets to the component scores from the full dataset by running Pearson correlations such that higher correlation coefficients indicate higher component reliability (see Mulholland et al., 2023 for a similar method of estimating component reliability).

To examine the relationship between these components and transportation per se, we then ran correlations between the component scores and participants' responses to the TS-SF scale given to them at the end of the experiment.

To investigate the relationship between these components and the valence of the text, we ran *linear mixed effects models* using the lme4 package (Bates et al., 2015). A linear model was run for each component, with the valence of the text as a categorical predictor and neutral texts as the baseline, as well as random intercepts and slopes for items and participants. To investigate the relationship

Table 2
Component correlation matrix with oblimin rotation.

Component	1	2	3	4
1	1.000	−0.147	−0.003	0.093
2		1.000	0.032	0.058
3			1.000	0.030
4				1.000

between components and reading comprehension accuracy, we ran a generalized linear mixed effect model with the four components as predictors, as well as random slopes for items and participants.

Lastly, we investigated the relationship between eye-movement measures and the thought components from the PCA. Prior to analysis, all fixations shorter than 50 ms and longer than 1000 ms were excluded from the eye movement data (0.87 % of all fixations). The data was checked and corrected for line-drifting with the PopEye package for R (Schroeder, 2019), and three eye movement measures were computed from the data: gaze duration, skipping rate, and go-past time. Gaze duration is the sum of all fixation durations landing on a word during its first-pass reading. Skipping rate is a dichotomous variable reflecting whether the word was skipped during first-pass reading or not. Go-past time is the time spent reading the word and any preceding parts of text before the reader moves on in text. Duration measures were log-transformed before the analyses.

To investigate the relationship between participants' thoughts and eye-movement behaviour, we used ***generalized additive mixed models*** (GAMMs). GAMMs are used to model non-linear relationships between variables (Baayen et al., 2017; Wieling, 2018; Wood, 2017) and are particularly powerful as there is no a-priori for the type of non-linear relationship between variables (e.g., polynomial) and also allows for linear relationships to be investigated if a linear relationship fits the data better than a non-linear one (Baayen et al., 2017; Wieling, 2018; Wood, 2017). Based on visual inspection of the relationship between our variables (see Figs. 2-4), we decided to use GAMMs as non-linear regression seemed appropriate to model the relationship between participants' thoughts and eye movements.

For each component identified with the PCA, we ran models for three eye-movement measures: gaze duration, skipping rate, and go-past time. We controlled for word length as a linear effect, and included word frequency, component score, and their interaction as non-linear predictors. In addition, we added random effects for participant and words and compared models following the method described in Wieling (2018), only adding random effects if they improved the model (i.e., were significant). Adding these random effects takes into account the nested structure of the mDES response data on which the PCA was run. The generalized additive models were run with the '*mgcv*' package (version 1.8–40; Wood 2011, 2017), and visualization of the non-linear effects were plotted using the '*itsadug*' package (version 2.4; van Rij et al., 2022).

2.8. Transparency and openness

We report all data exclusions, manipulations, and measures in the study. The dataset and analyses code are available at: https://osf.io/kd8xa/. The text materials are not available as they are copyrighted. All analyses were run in R (R core Team, 2022). This study's

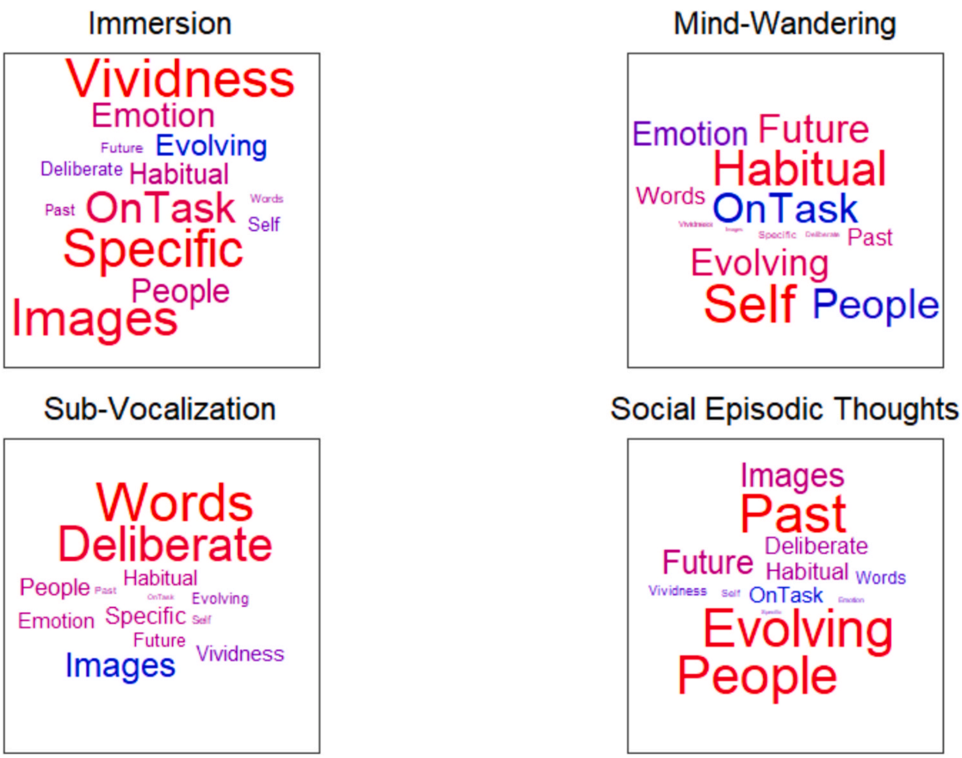

Fig. 1. Word Clouds for each Component. Note. Fig. 1 shows word-clouds that illustrate the contents of the thoughts according to the four components. The size of the words represents their loadings with bigger words indicating higher component loadings, and the color represents the direction of the relationship with more red words loading positively onto the component and blue words loading negatively onto the component. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

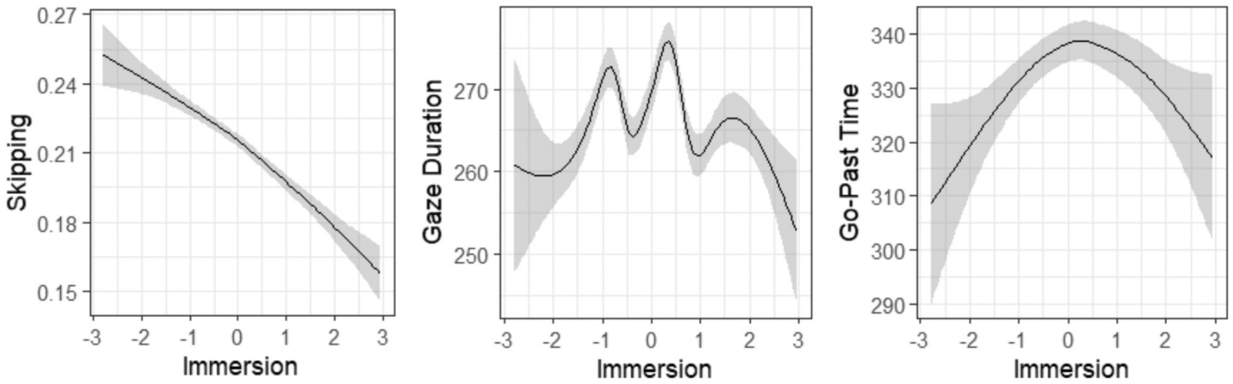

Fig. 2. Relationship between Immersion and Eye Movements. Note. Fig. 2 shows the relationship between eye-movement measures and component scores for the immersion component.

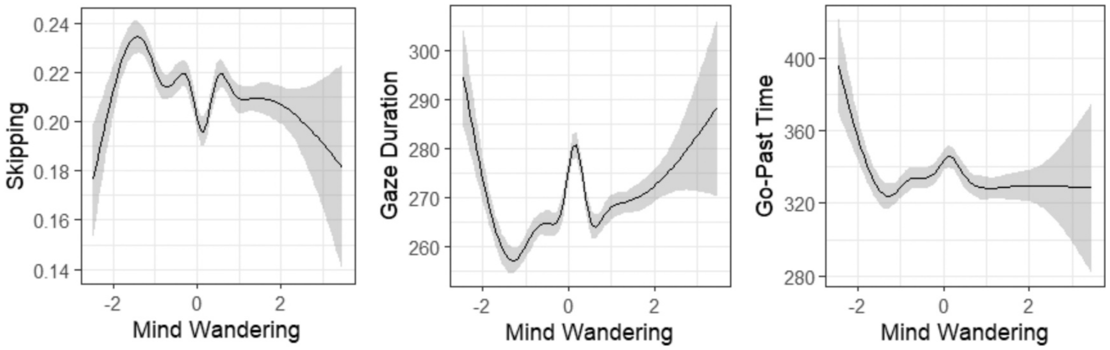

Fig. 3. Relationship between Mind-Wandering and Eye Movements. Note. Fig. 3 shows the relationship between eye-movement measures and component scores for the mind-wandering component.

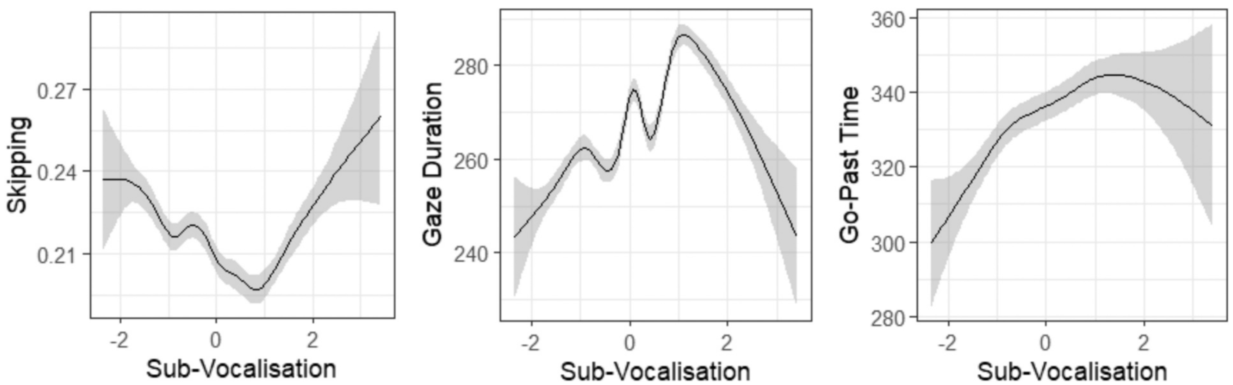

Fig. 4. Relationship between Sub-Vocalization and Eye Movements. Note. Fig. 4 shows the relationship between eye-movement measures and component scores for the sub-vocalization component.

design and analysis were not pre-registered.

3. Results

3.1. Identifying readers' thoughts: Principal component analysis

Results from the principal component analysis on participants' responses to the mDES scale indicated four components that explained 51 % of the variance in our data. The loadings for these four components are shown in Table 3. Component 1, "*immersion*", consists of thoughts that were task-related, detailed, with higher levels of imagery, along with generally positive emotions. Component 2, "*mind wandering*", consists of episodes where participants were off task, with reoccurring thoughts about the future and themselves, and generally negative emotions. Component 3, "*sub-vocalization*", consists of voluntary verbal thoughts. Lastly, Component 4, "*social episodic thoughts*", consists of evolving thoughts about the past and other people. A visualization of these components is shown in Fig. 1 as word-clouds indicating the importance of different aspects of thoughts for each component.

Results from the correlations between scores calculated on the full dataset and scores calculated on the split-half datasets generally indicated good component reliability with an average of 0.88. Reliability was particularly high for the immersion, mind-wandering, and sub-vocalization components with coefficients of 0.91, 0.93, and 0.96 respectively. Reliability was somewhat lower for the social episodic thoughts component with a coefficient of 0.70.

Correlations between these components and participants' responses to the TS-SF scale given at the end of the experiments indicated that scores from Component 1 ("immersion") were correlated with transportation scores, $r(54) = 0.56$ 95 %CI[0.34, 0.71], $p < 0.001$, suggesting that this component may indeed be indicative of immersive thoughts. None of the other components were significantly correlated with the transportation scores (all $ps > 0.05$).

Correlations between these components and participants' pleasantness ratings at the end of the experiment indicated that scores from Component 1 ("immersion") were positively correlated with pleasantness ratings $r(54) = 0.33$ 95 %CI[0.07, 0.55], $p = 0.013$, suggesting that this component may be indicative of a more positive experience during the study. This is in line with the idea that immersion is typically associated with a positive reading experience. Neither components 2 or 3 were significantly correlated with pleasantness scores (both $ps > 0.05$). However, Component 4 ("social episodic thoughts") was positively correlated with pleasantness ratings, $r(54) = 0.30$, 95 %CI[0.04, 0.52] $p = 0.026$. This suggests that this component is also associated with a more positive experience.

3.2. The relationship between text valence and thought types

Descriptive statistics of the component scores for each text valence category are shown in Table 4. Scores for Component 1 (immersion) were higher for positive paragraphs compared to neutral paragraphs ($b = 0.36$, $t = 3.15$). There were no differences between negative paragraphs and neutral or positive paragraphs. There were no significant effects of text valence on Component 2 ("mind-wandering"). Scores for Component 3 ("sub-vocalization") were significantly higher for both positive (b = -0.12, t = -2.29) and negative paragraphs compared to neutral paragraphs (b = -0.16, t = -3.16). There were no significant effects of text valence on Component 4 ("social episodic thoughts").

3.3. The relationship between comprehension and though types

Participants responded with an average of 79 % accuracy to the memory questions following each probe (range 47 % − 97 %). We found no significant effect of any of the component scores on participants' response accuracy. The output of the model is shown in Table 5.

3.4. The relationship between eye-movement behaviour and thought types

The relationship between each component identified with the PCA and three eye-movement measures are presented in Figs. 2–4. As shown in the figures, these relationships were often non-linear, and differed across components.

As illustrated in Fig. 2, there was a negative linear relationship between skipping and immersion, such that higher immersion scores were associated with lower skipping rates. Gaze duration was non-linearly related to levels of immersion with a globally upward

Table 3
Component loadings extracted with the principal component analysis.

	Component 1	Component 2	Component 3	Component 4
Q1: Task	0.54	−0.45	0.02	−0.10
Q2: Future	−0.06	0.40	0.10	0.24
Q3: Past	0.07	0.13	0.03	0.63
Q4: Self	−0.10	0.77	0.03	−0.02
Q5: People	0.28	−0.44	0.15	0.59
Q6: Emotion	0.32	−0.29	0.12	−0.01
Q7: Images	0.70	0.01	−0.32	0.23
Q8: Words	0.04	0.15	0.79	−0.06
Q9: Vividness	0.80	0.02	−0.13	−0.04
Q10: Specific	0.77	0.03	0.14	0.01
Q11: Habit	0.23	0.67	0.13	0.13
Q12: Evolving	−0.24	0.35	−0.06	0.60
Q13: Deliberate	−0.09	−0.01	0.65	0.11
SS Loadings	2.33	1.85	1.25	1.26
Proportion of Variance	0.18	0.14	0.10	0.10
Cumulative Variance	0.18	0.32	0.42	0.51

Table 4
Mean component scores per text valence category.

Valence	Immersion	Mind-Wandering	Sub-vocalization	Social Episodic Thoughts
Neutral	−0.06 (0.96)	0.03 (0.99)	−0.08 (1.02)	0.06 (1.01)
Negative	−0.14 (1.03)	0.11 (1.03)	0.09 (1.04)	0.03 (1.04)
Positive	0.24 (1.00)	−0.07 (1.01)	−0.03 (1.00)	−0.11 (1.05)

Table 5
Output of the model predicting comprehension from thought components.

	Comprehension Accuracy			
Predictors	*B*	*SE*	*CI*	*t*
(Intercept)	5.68	1.29	3.63 – 8.87	7.63
RC1	1.13	0.10	0.95 – 1.34	1.43
RC2	1.01	0.08	0.86 – 1.18	0.10
RC3	1.05	0.09	0.89 – 1.23	0.57
RC4	1.04	0.08	0.89 – 1.22	0.51

pattern and several peaks. Go-past time varied along a bell-shaped curve with immersion levels. In contrast, mind-wandering was non-linearly related to skipping rates (See Fig. 3), with an overall downward curve and some peaks. Mind-wandering also showed a downward pattern for gaze duration with a peak around 0 followed by an upwards slope. Lastly, mind-wandering also showed a non-linear pattern for go-past time with a downward slope followed by a flattening of the curve. Sub-vocalization had a non-linear, u-shaped association with skipping rates (Fig. 4). The relationship to gaze duration was similar to that of immersion, with a generally upward pattern with several peaks followed by a steep decline. The relationship to go-past time was smoother with an inverted u-shape curve. Finally, in Fig. 5, the relationship between social episodic thoughts and skipping was similar to immersion with a linear negative association such that higher scores of social episodic thoughts were associated with lower skipping rates. There was an inverted u-shaped relationship between gaze duration and social episodic thoughts. Lastly, the relationship between social episodic thoughts and go-past time was mostly linear with an upward slope.

Based on these visualizations, we decided to use GAMMs to model the relationship between eye movements and thought types, as this method allows for non-linear relationship to be investigated. The output of models investigating differences in eye-movement measures and the word-frequency effect between the four types of thoughts (immersion, wind-wandering, sub-vocalization, and social episodic thoughts) is shown in Tables 5-8. Across models, the word length and word frequency effects were always significant. As this article focuses on the effect of the types of thoughts identified with the principal component analysis, only main effects and interactions with these components are discussed here.

In the models with immersion as a predictor, higher immersion was associated with a lower probability of skipping (edf = 1.0, $X^2 = 7.6$, p = 0.006). As for gaze duration, there was a significant interaction between word frequency and immersion (edf = 4.1, $F = 3.1$, p = 0.008), such that the size of the word-frequency effect varied non-linearly according to levels of immersive thoughts. This interaction is illustrated in Fig. 6, and suggests the word frequency effect was present only for words within the medium to low-frequency bands (100 ms difference between log frequencies of −1 and −4) when immersion levels were low, and that this effect lessened non-linearly with higher levels of immersion, with a difference of only about 50 ms between high frequency words (log frequency of 1) and low frequency words (log frequency of −4). In addition, while there was no frequency effect for words in the higher frequency bands (log frequency of 0 and higher) with low levels of immersion, the frequency effect was present for such words with high levels of immersion. We failed to observe statistically significant effects for go-past time.

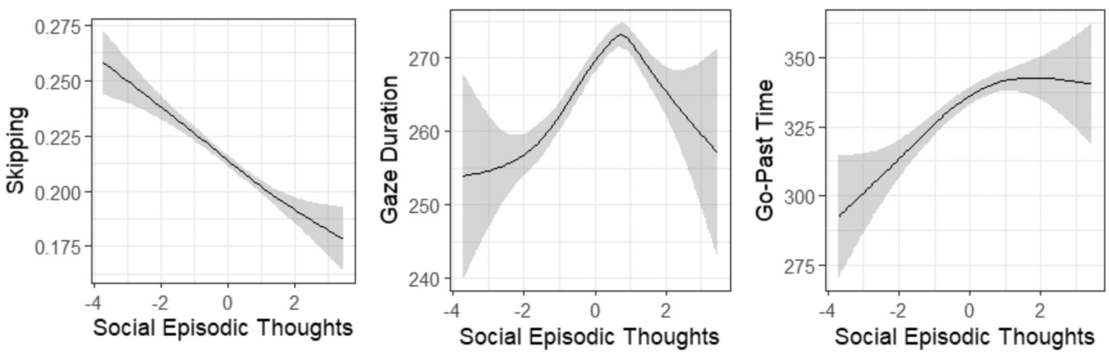

Fig. 5. Relationship between Social Episodic Thoughts and Eye Movements. Note. Fig. 5 shows the relationship between eye-movement measures and component scores for the social episodic thoughts component.

Table 6
Model outputs for the immersion component.

Predictor	Gaze Duration		Skipping		Go-Past Time	
	edf	p-value	edf	p-value	edf	p-value
Word Length (linear)	**NA**	**< 0.001**	**NA**	**< 0.001**	**NA**	**< 0.001**
Word Frequency	**3.9**	**< 0.001**	**1.7**	**< 0.001**	**1**	**< 0.001**
Immersion	1	0.460	**1**	**0.006**	2.0	0.578
Word frequency x immersion	**4.1**	**0.008**	1	0.111	1	0.112
Participant, Immersion	*147.8*	*< 0.001*	*120.2*	*< 0.001*	*138.7*	*< 0.001*
Participant, frequency	*50.8*	*< 0.001*	*179.6*	*0.002*	*49.5*	*< 0.001*
Word (intercept)	*1381.1*	*< 0.001*	*875.0*	*< 0.001*	*1400.5*	*< 0.001*
Word Immersion	*109.6*	*0.002*	*41.0*	*< 0.001*	*109.0*	*< 0.017*

Note. Table 6 shows the output of the GAMMs models for the immersion component, including linear and non-linear effects. Predictors in italic are random effects. Edf values indicate the degree of non-linearity, with values higher than 1 indicating that the effect is non-linear.

Table 7
Model outputs for the mind wandering component.

Predictor	Gaze Duration		Skipping		Go-Past Time	
	edf	p-value	edf	p-value	edf	p-value
Word Length (linear)	**NA**	**< 0.001**	**NA**	**< 0.001**	**NA**	**< 0.001**
Word Frequency	**3.9**	**< 0.001**	**1.8**	**< 0.001**	**1.8**	**< 0.001**
Mind Wandering	1.2	0.167	1.0	0.480	2.6	0.092
Word frequency x mind wandering	1.0	0.789	2.9	0.550	4.0	0.245
Participant, mind wandering	*116.9*	*< 0.001*	*118.3*	*< 0.001*	*109.0*	*< 0.001*
Participant, frequency	*50.8*	*< 0.001*	*180.1*	*< 0.001*	*184.7*	*< 0.001*
Word (intercept)	*1381.9*	*< 0.001*	*876.3*	*< 0.001*	*1400.7*	*< 0.001*
Word mind wandering	*77.4*	*0.03*	*NA*	*NA*	*178.7*	*< 0.001*

Note. Table 7 shows the output of the GAMMs models for the mind-wandering component, including linear and non-linear effects. Predictors in italic are random effects. Edf values indicate the degree of non-linearity, with values higher than 1 indicating that the effect is non-linear.

Table 8
Model outputs for the sub-vocalization component.

Predictor	Gaze Duration		Skipping		Go-Past Time	
	edf	p-value	edf	p-value	edf	p-value
Word Length (linear)	**NA**	**< 0.001**	**NA**	**< 0.001**	**NA**	**< 0.001**
Word Frequency	**3.8**	**< 0.001**	**1.7**	**< 0.001**	**1.7**	**< 0.001**
Sub-Vocalization	1.0	0.362	1.0	0.660	1.0	0.350
Word frequency x Sub-Vocalization	**6.0**	**0.026**	1.9	0.463	3.5	0.122
Participant, Sub-Vocalization	*111.7*	*< 0.001*	*91.8*	*< 0.001*	*94.5*	*< 0.001*
Participant, frequency	*50.9*	*< 0.001*	*180.8*	*< 0.001*	*182.7*	*< 0.001*
Word (intercept)	*1382.9*	*< 0.001*	*878.6*	*< 0.001*	*1401.9*	*< 0.001*
Word Sub-Vocalization	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

Note. Table 8 shows the output of the GAMMs models for the Sub-Vocalization component, including linear and non-linear effects. Predictors in italic are random effects. Edf values indicate the degree of non-linearity, with values higher than 1 indicating that the effect is non-linear. Random slopes for words did not improve model fits hence they were not included in these models.

In the models with levels of mind wandering as a predictor, there were no significant effects of mind wandering on any of the eye-movement measures, nor any significant interactions.

In the models with sub-vocalization as a predictor, there was a significant interaction between sub-vocalization and word frequency on gaze duration (edf = 5.9, $F = 2.2$, p = 0.026), such that the word-frequency effect varied non-linearly according to levels of sub-vocalization. This interaction is illustrated in Fig. 7, and shows that the word frequency effect was larger for lower levels of sub-vocalization.

In the models with social episodic thoughts as a predictor, there was a significant effect of social episodic thoughts on skipping (edf

Table 9
Model outputs for the social episodic thoughts component.

Predictor	Gaze Duration		Skipping		Go-Past Time	
	edf	p-value	edf	p-value	edf	p-value
Word Length (linear)	**NA**	**< 0.001**	**NA**	**< 0.001**	**NA**	**< 0.001**
Word Frequency	**3.9**	**< 0.001**	**1.7**	**< 0.001**	**2.0**	**< 0.001**
social episodic thoughts	3.5	0.361	**1.0**	**0.022**	3.2	0.360
Word frequency x social episodic thoughts	1.8	0.518	**2.1**	**0.008**	**1.0**	**0.041**
Participant, social episodic thoughts	*142.1*	*< 0.001*	*129.7*	*< 0.001*	*154.6*	*< 0.001*
Participant, frequency	*50.8*	*< 0.001*	*181.9*	*< 0.001*	*49.9*	*< 0.001*
Word (intercept)	*1382.5*	*< 0.001*	*875.7*	*< 0.001*	*1401.7*	*< 0.001*
Word social episodic thoughts	*77.4*	*0.046*	*62.0*	*< 0.001*	*NA*	*NA*

Note. Table 9 shows the output of the GAMMs models for the social episodic thoughts component, including linear and non-linear effects. Predictors in italic are random effects. Edf values indicate the degree of non-linearity, with values higher than 1 indicating that the effect is non-linear.

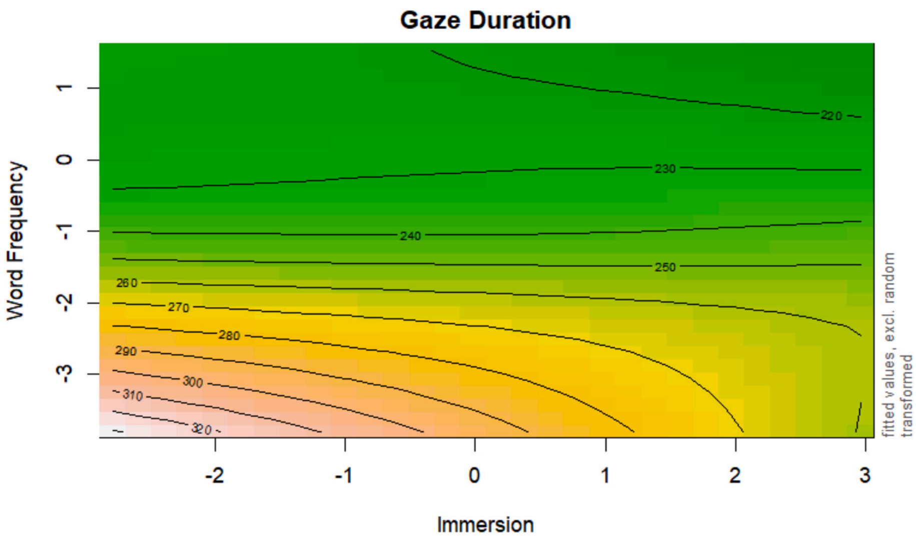

Fig. 6. Interaction between Immersion and Word Frequency on Gaze Duration. Note. Fig. 6 shows the non-linear interaction between word frequency and immersion on gaze duration. The gradient colors illustrate the size of the effect (red: higher values of gaze duration, green: lower values of gaze duration). The lines delimit areas where the effect is the same across immersion and word frequency values. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

= 1.0, $X^2 = 5.3$, p = 0.022). The effect was linear, such that skipping rates decreased with higher levels of social episodic thoughts. There was also a significant interaction between word frequency and social episodic thoughts on skipping rates (edf = 2.1, $X^2 = 11.0$, p = 0.008), as the word frequency effect tended to decrease with higher levels of social episodic thoughts (see Fig. 8). In addition, there was a significant interaction between word frequency and social episodic thoughts on go-past times (edf = 1.0, F = 4.2, p = 0.041), such that the word frequency effect tended to be lower for higher levels of social episodic thoughts (see Fig. 9).

4. Discussion

4.1. Readers' thought patterns during reading

Our study aimed to investigate the types of thought patterns readers have while reading a literary text, hoping to discriminate between states of immersed engagement in the text and states of off task mind-wandering in terms of the associated eye movement behavior while reading. Based on previous research, we expected that readers would experience immersive episodes when their attention would be focused on the content of the text and associated with vivid imagery (Gerrig, 1993; Green & Brock, 2000; Kuijpers et al., 2014; Ryan, 2001), and mind-wandering or "zoning-out" episodes characterized by thoughts unrelated to the text content (e.g., Smallwood, 2011). Our findings were in line with these predictions, and we identified four thought patterns experienced by readers. As expected, we identified a thought pattern that is in line with definitions of "immersion" or "transportation", namely thoughts related to

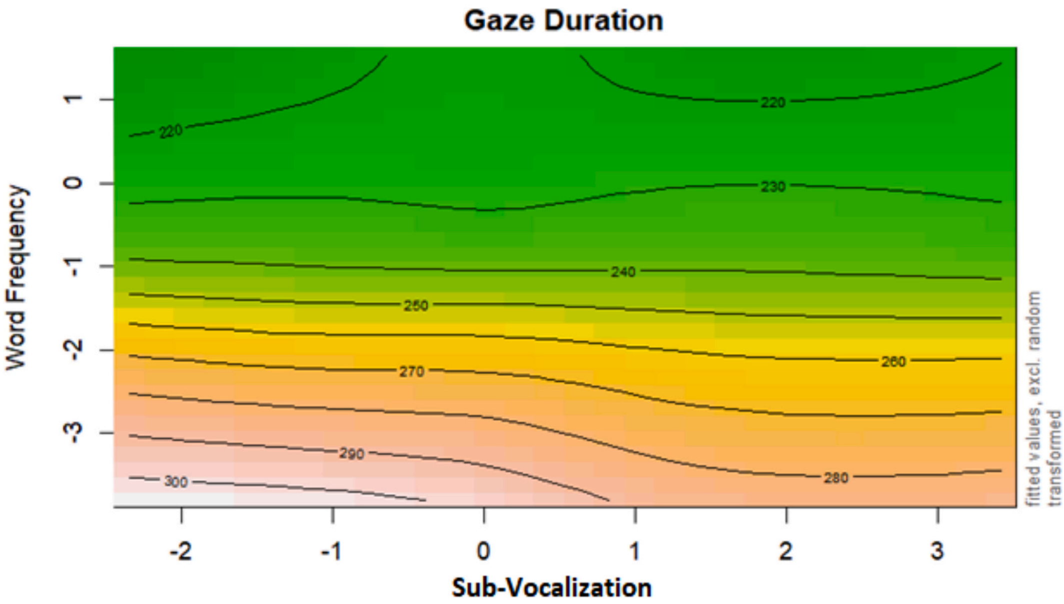

Fig. 7. Interaction between Sub-Vocalization and Word Frequency on Gaze Duration. Note. Fig. 7 shows the non-linear interaction between word frequency and sub-vocalization on gaze duration. The gradient colors illustrate the size of the effect (red: higher values of gaze duration, green: lower values of gaze duration). The lines delimit areas where the effect is the same across sub-vocalization and word frequency values. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

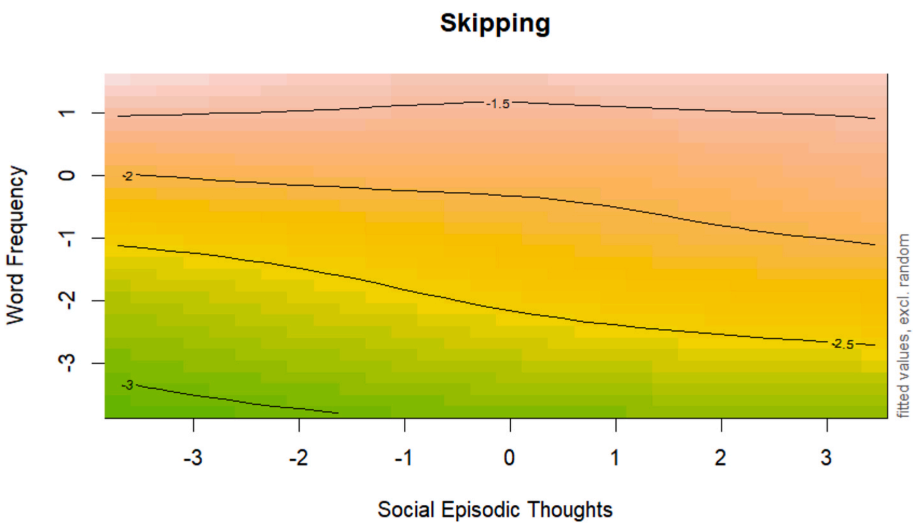

Fig. 8. Interaction between Social Episodic Thoughts and Word Frequency on Skipping. Note. Fig. 8 shows the non-linear interaction between word frequency and social episodic thoughts on skipping rates. The gradient colors illustrate the size of the effect (red: higher skipping rates; green = lower skipping rates). The lines delimit areas where the effect is the same across social episodic thoughts scores and word frequency values. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the text (i.e., “on task”), characterized by detailed and vivid images, and associated with positive emotions. The component scores on immersion were positively correlated with experienced transportation and reading pleasure reported after reading, validating the interpretation of this component as indicative of immersion.

We also identified thought patterns corresponding to mind-wandering, namely thoughts unrelated to the text (i.e., off task), characterized by reoccurring thoughts about oneself and the future. Of the thought patterns identified in this study, this component most closely resembles off-task thoughts captured in previous studies of eye movement behavior while reading (e.g., Faber et al., 2020; Reichle et al., 2010; Steindorf & Rummel, 2020). However, as previous studies have only measured whether the reader’s thoughts were on or off task (or, whether the person was zoning out), the specific features of the experiences remain unknown. In our study, the use of mDES allowed us to establish that most of the time off-task thoughts included habitual, somewhat evolving thoughts related to self and

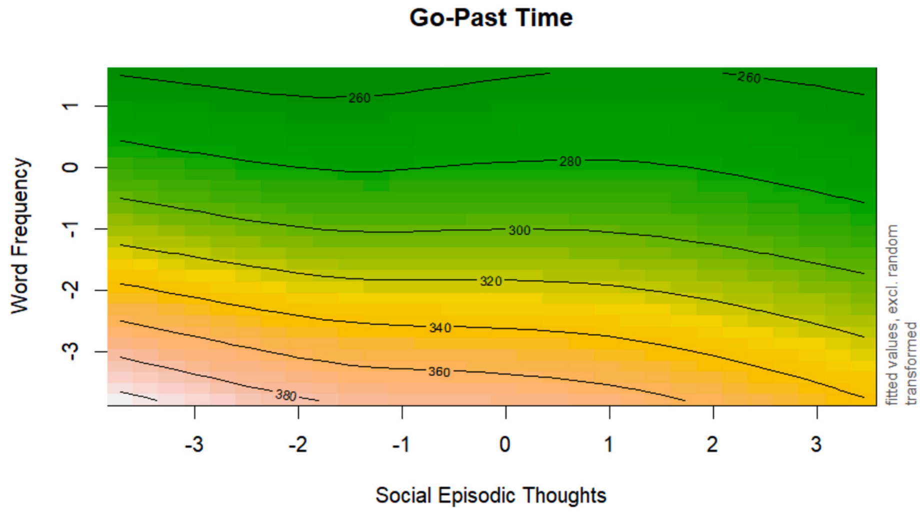

Fig. 9. Interaction between Social Episodic Thoughts and Word Frequency on Go-Past Time. Note. Fig. 9 shows the non-linear interaction between word frequency and social episodic thoughts on go-past time. The gradient colors illustrate the size of the effect (red: higher values of go-past time, green: lower values of go-past time). The lines delimit areas where the effect is the same across social episodic thoughts and word frequency values. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

future. Unexpectedly, we did not observe a negative correlation between mind-wandering and correct responses to text memory questions, which we should have observed if mind-wandering interferes with forming a memory representation of the text (Smallwood, 2011). A possible reason is that the questions were easy and presented immediately after the text paragraph, when the text contents were still fresh in memory.

One thought pattern, which we termed "sub-vocalization", was characterized by deliberate verbal thoughts. One possible explanation for this type of thought might be that readers were focusing on their "inner voice" reading the text. However, it is unclear whether these thoughts were directly related to the stimuli and or/task, or whether they are reflective of something else (e.g., voluntary mind-wandering). Hence, more research should be carried out to better understand what this thought pattern represents, and whether it falls within the "mind-wandering" family (e.g., text-related mind-wandering; voluntary mind-wandering; Seli et al., 2018).

Lastly, we identified a thought pattern which we termed "social episodic thoughts" which was characterized by evolving thoughts about the past and other people, and which was associated with a pleasant reading experience. As for the sub-vocalization component, it is possible that these thoughts are related to the text, such as the story triggering memories of previous events/story (Fabry & Kukkonen, 2019). The absence of a strong negative weighting on the "On Task" dimension (see Fig. 1) makes it unlikely that this is an example of off-task mind-wandering. Prior studies have shown that this component of thought engages the medial prefrontal cortex (Konu et al., 2020) is important in tasks that rely on social cognition (Konu et al., 2021, McKeown et al., 2025) and in daily life occur during social interactions (Mulholland et al., 2023). In the context of these prior studies, this pattern of social episodic thought may reflect a form of social cognition that is engaged when we read stories about other people.

Taken together, by using mDES to capture a wide range of experiential features we were able to establish that readers experience multiple kinds of thought patterns during reading, including but not limited to the "on or off" task dichotomy often used in mind-wandering research. Indeed, we found that while readers did experience "zoning out", they also experienced immersive episodes, as well as other types of thoughts that may or may not be related to the stimuli and/or task. These findings are in line with Seli et al. (2018) argument that mind-wandering should be seen as an umbrella term for different types of thought patterns that may or may not be related to the stimuli (i.e., the text) and/or the task (i.e., reading). In this context the capacity for mDES to characterize both task relevant and task irrelevant states is a useful tool for better understanding the landscape of thought patterns that emerge during reading, whether they are beneficial or detrimental to the act of comprehending what we are reading, as well as how they may influence objective indicators of text processing.

4.2. The influence of text valence on readers' thought patterns

The second aim of this study was to investigate the influence that a text's valence has on the occurrence of different types of thought patterns during the reading of literary texts. We found that readers were more likely to be immersed in the story while reading positive paragraphs compared to neutral paragraphs. This is partially in line with previous studies showing that emotional texts tend to be associated with higher levels of immersion (e.g., Ballenghein et al., 2023; Kaakinen & Simola, 2020). However, unlike in previous studies (Ballenghein et al., 2023; Kaakinen & Simola, 2020), we did not find that negative paragraphs induce higher immersion than neutral text. In the previous studies, the negative text materials were Stephen King horror stories, representing a genre that is likely to induce feelings of suspense and more immersion (Jacobs, 2015). The text in the present study was a novel describing the life of a young female moving to New York City in the 1970′s, where negative text paragraphs were mostly descriptive and did not contain suspense-inducing content. The results thus provide further evidence that emotional texts and positive texts in particular are more likely to induce transportation compared to neutral texts, and that the emotionality and the genre of a narrative should be taken into account when investigating text processing.

Interestingly, we also found a negative relationship between emotional texts, both positive and negative, and the "sub-vocalization" component (i.e., voluntary verbal thoughts), such that neutral text led to lower levels of sub-vocalization than emotionally arousing positive or negative text. As noted earlier, a plausible interpretation of this thought pattern might be readers' focusing their attention to their "inner voice" during reading, which may be a behaviour associated more with instances where the text is more engaging (i.e. higher valence and arousal). Another possibility is that readers sometimes "sound-out" the text through sub-vocalization (i.e., paying attention to their inner voice) in order to get a sense of the emotional valence of the text.

Of note, we did not find any influence of the emotionality of the text on mind-wandering. While some studies suggests that mind-wandering or zoning out may be more likely to occur in instance where the text is deemed less engaging by the reader (e.g., boring texts: Danckert et al., 2018), our results suggests that emotional texts do not lead to reduced instances of mind-wandering during reading.

Lastly, we found no association between the "social episodic thoughts" component and text valence. This result would be in line with an interpretation of this thought pattern as reflecting memories triggered by the contents of the text, or integration of background knowledge with the text. Indeed, if this is the case, such thoughts are likely to be triggered by all types of text contents regardless of their emotional valence, whether it be neutral (e.g. "I have seen the place where the story takes place"), positive (e.g., "I remember what being in love for the first time feels like"), or negative (e.g., "I know what a painful breakup feels like").

4.3. Eye movements during immersion and mind-wandering

The third aim of this study was to examine the relationship between readers' thought patterns while reading literary texts and their eye-movement behaviour. Firstly, we found that higher levels of immersion were associated with lower skipping rates. This is in line with the idea that immersion is characterized by instances where attention is absorbed by the text content, leading to more words being fixated (Gerrig, 1993; Green & Brock, 2000). Interestingly, while fewer words were skipped, readers did not seem to fixate them for longer as we found no effect of levels of immersion on either gaze duration or go-past time. These findings contrast with Jacobs' (2015) predictions that immersion would be associated with longer saccades and shorter fixations. Indeed, low skipping rates likely indicate that readers make shorter saccades due to not skipping words. Nevertheless, we found a non-linear effect of word frequency on gaze duration, such that the frequency effect is generally reduced during high immersion. This was particularly true for words within the lower frequency bands, such that there was no effect of word frequency between words with a log frequency of -2 or lower. This is in line with previous findings that readers are less sensitive to word characteristics with higher levels of narrative absorption and liking (Eekhof et al., 2021).

Interestingly, we did not find any relationship between levels of mind-wandering and eye-movement behaviour. This is in contrast to previous research showing that mind-wandering influences eye movements during reading, and that mind-wandering is characterized by reduced effects of word characteristics (e.g., Reichle et al., 2010; Foulsham et al., 2013). However, it is likely that differences in our results is due to methodological differences between previous work and our study. Indeed, previous research typically analyzed the effect of mind-wandering on eye-movement behaviour by comparing eye movements during "on-task" reading and "off-task" or "mindless" reading, such that the difference was between two categorical conditions. However, in the present study mind-wandering was computed as a continuous variable rather than a categorical one, such that we examined the relationship between degrees of mind-wandering and eye-movement behaviour, and did not directly contrast mind-wandering with on-task reading. Hence it may be that while eye-movement behaviour during mindless reading does differ from eye movements during "on-task" reading, eye movements may not differ significantly relative to the degree to which a reader is off-task.

The results for the sub-vocalization component also showed a reduced effect of word frequency on gaze duration, particularly for high levels of sub-vocalization and for words within the lower frequency bands (-2 log frequency and lower). This would be in line with the interpretation that this component reflects higher attention paid to lexical processing, or a readers' "inner voice" while reading. Unlike the immersion component, however, there was no influence of sub-vocalization on skipping behavior. More research is necessary in order to better understand what this component reflects, and how it affects lexical processing during reading.

Lastly, higher levels of social episodic thoughts were associated with lower skipping rates, as well as a reduced effect of word frequency on skipping and go-past time. As with immersion and sub-vocalization, this suggests that social episodic thoughts influence the fluency of lexical processing, but that the effect might occur at later stages of the reading process compared to immersion and sub-vocalization. This finding is in line with an interpretation of this component as reflecting integration of the content of the text with world knowledge or previous experiences (Fabry & Kukkonen, 2019). However, more research is necessary in order to better understand what this component reflects, and how it influences later stages of the reading process such as semantic integration or inference making and the possible integration of world or personal experience with the events of the narrative. It is also possible that the social features of this component of thought make it particularly important in a text with a clear protagonist (like the one used in the current study).

5. Conclusions

Although our study provides important information on the different features of experience that emerge while reading a narrative rich text, there are nonetheless important open questions that remain. First, we used only a single text so it remains unclear how these findings would generalize to other texts, including those with a different purpose (e.g. scientific texts). It is possible that in this context, task irrelevant experiences like mind-wandering may be more important and could possibly make a greater contribution to reading behavior. Second, our study was conducted in a population of Finnish readers but focused on a text about living in New York, and it could be possible that experiences would vary if people had more direct experience with the subject matter of what was being read (e.g. Smallwood et al., 2009). Third, we used mDES to capture a broad range of experiences that emerge while reading which defines experiential states as a series of dimensions which characterize significant variation in the self-reported data. This approach contrasts with traditional approaches that focus only a specific predefined features of experience (e.g. like zoning out, Smallwood et al., 2008). Our approach has several advantages over traditional methods. For example, by sampling multiple features of experience we can capture the landscape of experiences that emerge in a specific context in a way that is not possible in a study that targets only specific aspects of cognition (such as off task thought or mind-wandering). This approach is generalizable across contexts since it can be applied during laboratory tasks including reading, movie watching (Wallace et al., 2024), during brain imaging studies (e.g. Konu et al., 2020; Turnbull et al., 2019) and as people go about their daily lives (McKeown et al., 2020; Mulholland et al., 2023). This generality is achieved because mDES defines experiential states as emergent properties of the weighting of several questions rather than captured by specific questions. Other approaches which target specific aspects of experience in a single question are less generalizable because states that emerge during reading (such as immersion) would be less useful when studying states of sustained attention (where boredom rather than immersion is most likely the most common states. One important consequence of this generalizability of mDES is to allow thought patterns in different situations to be explicitly compared, identifying patterns of experience that are generalizable across situations to be explicitly identified (McKeown et al., 2025), helping identify the ecological validity of laboratory situations (Chitiz et al., 2025) and using tasks to identify the most likely cognitive processes to underpin covert states (McKeown et al., 2023). However, this approach uses data driven methods to characterize mental states and so is at odds with attempts to define mental states in a principled manner (e.g. Christoff et al., 2018). Fortunately, in the future it could be possible to build sufficiently large data sets (possibly using data gathered in the real world to ensure ecological validity) to identify the feature weightings that constitute the most important experiential states that humans engage in and to use these features as definitions of mental states in future studies of ongoing experience in reading and other task contexts.

Author contributions

Emilia Ranta, Johanna K. Kaakinen, Jonathan Smallwood, Jaana Simola and Karin Kukkonen were responsible for the design and conceptualization of the study. Emilia Ranta was responsible for creating the study materials, all data collection and cleaning. Diane Mézière was responsible for the data analysis and visualization of the results. Diane Mézière and Johanna Kaakinen were responsible for the interpretation of the results and writing of the original draft of the manuscript. All authors contributed to reviewing and editing the manuscript.

CRediT authorship contribution statement

Diane Mézière: Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Formal analysis. **Johanna K. Kaakinen:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Emilia Ranta:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Karin Kukkonen:** Writing – review & editing, Conceptualization. **Jonathan Smallwood:** Writing – review & editing, Methodology, Conceptualization. **Jaana Simola:** Writing – review & editing, Methodology, Conceptualization.

Funding

The research reported in this paper was funded by Research Council of Finland grant number 334266.

Data availability

The dataset and analyses code are available at: https://osf.io/kd8xa/. The text materials are not available as they are copyrighted.

References

Appel, M., Gnambs, T., Richter, T., & Green, M. C. (2015). The transportation scale–short form (TS–SF). *Media Psychology, 18*(2), 243–266. https://doi.org/10.1080/15213269.2014.987400

Baayen, H., Vasishth, S., Kliegl, R., & Bates, D. (2017). The cave of shadows: Addressing the human factor with generalized additive mixed models. *Journal of Memory and Language, 94*, 206–234. https://doi.org/10.1016/j.jml.2016.11.006

Ballenghein, U., Kaakinen, J. K., Tissier, G., & Baccino, T. (2023). Fluctuation in cognitive engagement during listening and reading of erotica and horror stories. *Cognition and Emotion, 37*(5), 874–890. https://doi.org/10.1080/02699931.2023.2215974

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Bezdek, M. A., & Gerrig, R. J. (2017). When narrative transportation narrows attention: Changes in attentional focus during suspenseful film viewing. *Media Psychology, 20*(1), 60–89. https://doi.org/10.1080/15213269.2015.1121830

Bixler, R., & D'Mello, S. (2016). Automatic gaze-based user-independent detection of mind wandering during computerized reading. *User Modeling and User-Adapted Interaction, 26*(1), 33–68. https://doi.org/10.1007/s11257-015-9167-1
Bonifacci, P., Viroli, C., Vassura, C., Colombini, E., & Desideri, L. (2023). The relationship between mind wandering and reading comprehension: A meta-analysis. *Psychonomic Bulletin & Review, 30*(1), 40–59.
Bradley, M., & Lang, P. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9
Chitiz, L., Mckeown, B., Mulholland, B., Wallace, R., Goodall-Halliwell, I., Ping-Ho, N. S., & Smallwood, J. (2025). Mapping cognition across lab and daily life using experience-sampling. *Consciousness and cognition, 131*, Article 103853.
Christoff, K., Mills, C., Andrews-Hanna, J. R., Irving, Z. C., Thompson, E., Fox, K. C., & Kam, J. W. (2018). Mind-wandering as a scientific concept: Cutting through the definitional haze. *Trends in cognitive sciences, 22*(11), 957–959.
D'Mello, S. K., & Mills, C. S. (2021). Mind wandering during reading: An interdisciplinary and integrative review of psychological, computing, and intervention research and theory. *Language and Linguists Compass, 15*(4). Article e12412.
Danckert, J., Hammerschmidt, T., Marty-Dugas, J., & Smilek, D. (2018). Boredom: Under-aroused and restless. *Consciousness and Cognition, 61*, 24–37. https://doi.org/10.1016/j.concog.2018.03.014
Eekhof, L. S., Kuijpers, M. M., Faber, M., Gao, X., Mak, M., van den Hoven, E., & Willems, R. M. (2021). Lost in a story, detached from the Words. *Discourse Processes, 58*(7), 595–616. https://doi.org/10.1080/0163853X.2020.1857619
Faber, M., Bixler, R., & D'Mello, S. (2018). An automated behavioral measure of mind wandering during computerized learning. *Behavior Research Methods, 50*(1), 134–150. https://doi.org/10.3758/s13428-017-0857-y
Faber, M., Krasich, K., Bixler, R. E., Brockmole, J. R., & D'Mello, S. K. (2020). The eye–mind wandering link: Identifying gaze indices of mind wandering across tasks. *Journal of Experimental Psychology: Human Perception and Performance, 46*(10), 1201–1221. https://doi.org/10.1037/xhp0000743
Fabry, R. E., & Kukkonen, K. (2019). Reconsidering the mind-wandering reader: Predictive processing, probability designs, and enculturation. *Frontiers in Psychology, 2648*. https://doi.org/10.3389/fpsyg.2018.02648
Foulsham, T., Farley, J., & Kingstone, A. (2013). Mind wandering in sentence reading: Decoupling the link between the mind and the eye. *Canadian Journal of Experimental Psychology, 67*(1), 51–59. https://doi.org/10.1037/a0030217
Frank, D. J., Nara, B., Zavagnin, M., Touron, D. R., & Kane, M. J. (2015). Validating older adults' reports of less mind-wandering: An examination of eye movements and dispositional influences. *Psychology and Aging, 30*(2), 266–278. https://doi.org/10.1037/pag0000031
Gerrig, R. J. (1993). *Experiencing narrative worlds: On the psychological activities of reading. Routledge*. https://www.jstor.org/stable/j.ctt1dr37cb.
Ginter, F., & Laippala, V. (2017). Finnish Internet parsebank. A mass-scale corpus of Internet Finnish (pb_sane), which consists of 3043 million word tokens.
Green, M. C., & Brock, T. C. (2000). The role of transportation in the persuasiveness of public narratives. *Journal of Personality and Social Psychology, 79*(5), 701–721. https://doi.org/10.1037/0022-3514.79.5.701
Hustvedt, S. (2019). *Muistoja tulevaisuudesta* (K. Rikman, Suom.). Otava. (Alkuperäisteos julkaistu 2019).
Jacobs, A. M. (2015). Neurocognitive poetics: Methods and models for investigating the neuronal and cognitive-affective bases of literature reception. *Frontiers in Human Neuroscience, 9*, 1–22. https://doi.org/10.3389/fnhum.2015.00186
Kaakinen, J., & Simola, J. (2020). Fluctuation in pupil size and spontaneous blinks reflect story transportation. *Journal of Eye Movement Research, 13*(3), 1–14. https://doi.org/10.16910/jemr.13.3.6
Knickerbocker, H., Johnson, R. L., & Altarriba, J. (2015). Emotion effects during reading: Influence of an emotion target word on eye movements and processing. *Cognition and Emotion, 29*(5), 784–806. https://doi.org/10.1080/02699931.2014.938023
Konu, D., Mckeown, B., Turnbull, A., Ho, N. S. P., Karapanagiotidis, T., Vanderwal, T., & Smallwood, J. (2021). Exploring patterns of ongoing thought under naturalistic and conventional task-based conditions. *Consciousness and cognition, 93*, Article 103139.
Konu, D., Turnbull, A., Karapanagiotidis, T., Wang, H.-T., Brown, L. R., Jefferies, E., & Smallwood, J. (2020). A role for the ventromedial prefrontal cortex in self-generated episodic social cognition. *NeuroImage, 218*, Article 116977. https://doi.org/10.1016/j.neuroimage.2020.116977
Konishi, M., McLaren, D. G., Engen, H., & Smallwood, J. (2015). Shaped by the past: The default mode network supports cognition that is independent of immediate perceptual input. *PLoS One1, 10*(6), Article e0132209.
Kuijpers, M. M., Hakemulder, F., Tan, E. S., & Doicaru, M. M. (2014). Exploring absorbing reading experiences: Developing and validating a self-report scale to measure story world absorption. *Scientific Study of Literature, 4*(1), 89–122. https://doi.org/10.1075/ssol.4.1.05kui
Lei, A., Willems, R. M., & Eekhof, L. S. (2023). Emotions, fast and slow: Processing of emotion words is affected by individual differences in need for affect and narrative absorption. *Cognition and Emotion, 37*(5), 997–1005. https://doi.org/10.1080/02699931.2023.2216445
Mckeown, B., Goodall-Halliwell, I., Wallace, R., Chitiz, L., Mulholland, B., Karapanagiotidis, T., & Smallwood, J. (2025). Self-reports map the landscape of task states derived from brain imaging. *Communications psychology, 3*(1), 8.
Mckeown, B., Strawson, W. H., Wang, H. T., Karapanagiotidis, T., de Wael, R. V., Benkarim, O., & Smallwood, J. (2020). The relationship between individual variation in macroscale functional gradients and distinct aspects of ongoing thought. *NeuroImage, 220*, Article 117072.
Mckeown, B., Strawson, W. H., Zhang, M., Turnbull, A., Konu, D., Karapanagiotidis, T., & Smallwood, J. (2023). Experience sampling reveals the role that covert goal states play in task-relevant behavior. *Scientific reports, 13*(1), 21710.
Mulholland, B., Goodall-Halliwell, I., Wallace, R., Chitiz, L., Mckeown, B., Rastan, A., & Smallwood, J. (2023). Patterns of ongoing thought in the real world. *Consciousness and cognition, 114*, Article 103530.
Oyarzo, P., Preiss, D., & Cosmelli, D. (2022). Attentional and meta-cognitive processes underlying mind wandering episodes during continuous naturalistic reading are associated with specific changes in eye behavior. *Psychophysiology, 59*(4). https://doi.org/10.1111/psyp.13994. p. e13994-n/a.
R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*(3), 372–422. https://doi.org/10.1037/0033-2909.124.3.372
Reichle, E., Reineberg, A. E., & Schooler, J. W. (2010). Eye movements during mindless reading. *Psychological Science, 21*(9), 1300–1310. https://doi.org/10.1177/0956797610378686
Revelle, W. (2021). *psych: Procedures for Personality and Psychological Research*. Evanston, Illinois, USA: Northwestern University. Version = 2.1.9.
Ryan, M.-L. (2001). *Narrative as virtual reality: Immersion and interactivity in literature and electronic media*. Baltimore: Johns Hopkins University Press.
Schroeder, S. (2019). PopEye - an R package to analyse eye movement data from reading experiments. *GitHub repository*. https://github.com/sascha2schroeder/popEye.
Scott, G. G., O'Donnell, P. J., & Sereno, S. C. (2012). Emotion words affect eye fixations during reading. *Journal of Experimental Psychology: Learning Memory and Cognition, 38*(3), 783–792. https://doi.org/10.1037/a0027209
Seli, P., Kane, M. J., Smallwood, J., Schacter, D. L., Maillet, D., Schooler, J. W., & Smilek, D. (2018). Mind-wandering as a natural kind: A family-resemblances view. *Trends in Cognitive Sciences, 22*(6), 479–490. https://doi.org/10.1016/j.tics.2018.03.010
Sheikh, N. A., & Titone, D. A. (2013). Sensorimotor and linguistic information attenuate emotional word processing benefits: An eye-movement study. *Emotion, 13*(6), 1107–1121. https://doi.org/10.1037/a0032417
Sheikh, N. A., & Titone, D. A. (2016). The embodiment of emotional words in a second language: An eye-movement study. *Cognition and Emotion, 30*(3), 488–500. https://doi.org/10.1080/02699931.2015.1018144
Simola, J., Silander, T., Harju, M., Lahti, O., Makkonen, E., Pätsi, L. M., & Smallwood, J. (2023). Context independent reductions in external processing during self-generated episodic social cognition. *Cortex, 159*, 39–53.
Smallwood, J. (2011). Mind-wandering while reading: Attentional decoupling, mindless reading and the cascade model of inattention. *Language and Linguistic Compass, 5*(2), 63–77. https://doi.org/10.1111/j.1749-818X.2010.00263.x

Smallwood, J., Karapanagiotidis, T., Ruby, F., Medea, B., De Caso, I., Konishi, M., & Jefferies, E. (2016). Representing representation: Integration between the temporal lobe and the posterior cingulate influences the content and form of spontaneous thought. *PLoS One1, 11*(4), Article e0152272.

Smallwood, J., McSpadden, M., & Schooler, J. W. (2008). When attention matters: The curious incident of the wandering mind. *Memory & Cognition, 36*(6), 1144–1150. https://doi.org/10.3758/MC.36.6.1144

Smallwood, J., Nind, L., & O'Connor, R. C. (2009). When is your head at? An exploration of the factors associated with the temporal focus of the wandering mind. *Consciousness and cognition, 18*(1), 118–125.

Smilek, D., Carriere, J. S. A., & Cheyne, J. A. (2010). Out of mind, out of sight: Eye blinking is indicator and embodiment of mind wandering. *Psychological Science, 21*(6), 786–789. https://doi.org/10.1177/0956797610368063

Sormaz, M., Murphy, C., Wang, H.-t., Hymers, M., Karapanagiotidis, T., Poerio, G., Margulies, D. S., Jefferies, E., & Smallwood, J. (2018). Default mode network can support the level of detail in experience during active task states. *Proceedings of the National Academy of Sciences, 115*, 9318–9323.

SR Research Ltd. (2005). EyeLink 1000. [Apparatus and software]. https://www.sr-research.com/.

Steindorf, L., & Rummel, J. (2020). Do your eyes give you away? a validation study of eye-movement measures used as indicators of mindless reading. *Behavior Research Methods, 52*(1), 162–176. https://doi.org/10.3758/s13428-019-01214-4

Szpunar, K. K. (2017). Directing the wandering mind. *Current Directions in Psychological Science, 26*, 40–44. https://doi.org/10.1177/0963721416670320

Tabachnick, B. G., Fidell, L. S., & Ullman, J. B. (2007). *Using multivariate statistics* (Vol. 5,, 481–498.

Turnbull, A., Wang, H. T., Murphy, C., Ho, N. S. P., Wang, X., Sormaz, M., Bernhardt, B., Margulies, D. S., Vatansever, D., Jefferies, E., & Smallwood, J. (2019a). Left dorsolateral prefrontal cortex supports context-dependent prioritisation of off-task thought. *Nature Communications, 10*(1), 1–10. https://doi.org/10.1038/s41467-019-11764-y

Turnbull, A., Wang, H.-T., Schooler, J. W., Jefferies, E., Margulies, D. S., & Smallwood, J. (2019b). The ebb and flow of attention: Between-subject variation in intrinsic connectivity and cognition associated with the dynamics of ongoing experience. *NeuroImage, 185*, 286–299.

Uzzaman, S., & Joordens, S. (2011). The eyes know what you are thinking: Eye movements as objective measures of mind-wandering. *Consciousness and Cognition, 20*(4), 1882–1886. https://doi.org/10.1016/j.concog.2011.09.010

van Rij J, Wieling M, Baayen R, van Rijn H (2022*). itsadug: Interpreting Time Series and Autocorrelated Data Using GAMMs*. Rpackage version 2.4.1.

Wallace, R. S., Mckeown, B., Goodall-Halliwell, I., Chitiz, L., Forest, P., Karapanagiotidis, T., ... & Smallwood, J. (2024). Mapping patterns of thought onto brain activity during movie-watching. *bioRxiv*.

Wieling, M. (2018). Analyzing dynamic phonetic data using generalized additive mixed modeling: A tutorial focusing on articulatory differences between L1 and L2 speakers of English. *Journal of Phonetics, 70*, 86–116.

Wood, S. N. (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society (B), 73*(1), 3–36.

Wood, S. N. (2017). *Generalized Additive Models: An Introduction with R* ((2nd edition).). Chapman and Hall/CRC.

Yan, M., & Sommer, W. (2015). Parafoveal-on-foveal effects of emotional word semantics in reading Chinese sentences: Evidence from eye movements. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41*(4), 1237–1243. https://doi.org/10.1037/xlm0000095

Yan, M., & Sommer, W. (2019). The effects of emotional significance of foveal words on the parafoveal processing of N+ 2 words in reading Chinese sentences. *Reading and Writing, 32*(5), 1243–1256. https://doi.org/10.1007/s11145-018-9914-x

Zhang, H., Qu, C., Miller, K. F., Cortina, K. S., & Benjamin, A. S. (2020). Missing the joke: Reduced rereading of garden-path jokes during mind wandering. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 46*(4), 638–648. https://doi.org/10.1037/xlm0000745