The effect of disfluency on mind wandering during text comprehension

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Abstract

When reading, we frequently find ourselves thinking about something other than the text. These attentional lapses, known as mind wandering (MW), are negatively correlated with text comprehension. Previous studies have shown that more syntactically and semantically difficult texts elicit more MW, because textual difficulty impedes the construction of a mental model of the text, which makes it more difficult to suppress off-task thoughts. But is it possible to reduce MW without altering the content of the text itself? We hypothesized that reading a perceptually disfluent text might require more attentional resources, even if the content remains the same, leaving fewer resources available for MW. To test this idea, we manipulated the typeface (fluent: Arial or disfluent: Comic Sans) of two instructional texts on scientific research methods (each about 1490 words long), and found that mind wandering was less frequent when participants read the disfluent text. There were no comprehension differences among the fluent and disfluent groups. However, there was an indirect effect of disfluency on comprehension through mind wandering, suggesting that disfluency influences comprehension by enhancing attention. These findings provide insights on how processing difficulty and attention interact during reading comprehension.
1. Introduction

Attention is critical during reading because textual information needs to be integrated with an individual’s internal representations for comprehension to occur (Smallwood, Fishman, & Schooler, 2007). Lapses in attention cause a breakdown in this integration, leading to an impoverished representation of information and diminished comprehension (Smallwood et al., 2007; Smallwood, 2013). During these attentional lapses, attention might be directed towards internal self-generated thoughts and feelings. This phenomenon is known as mind wandering (MW) and is estimated to occur 20-40% of the time during reading (Smallwood et al., 2007).

Previous studies have shown that MW is consistently negatively associated with text comprehension (Feng, D’Mello, & Graesser, 2013; Smallwood et al., 2007). A reduction in MW would thus benefit comprehension, so it would be useful to identify factors that reduce MW. Several studies have shown that MW is less likely to occur under difficult versus easy conditions in the context of relatively simple sustained attention tasks (Smallwood, Obonsawin, & Heim, 2003; Smallwood, Obonsawin, & Reid, 2003). The idea is that task-related and internal self-generated thoughts (i.e., MW) compete for a limited pool of executive resources that direct attention, so more difficult tasks would be less susceptible to MW as they are less automated and consume more resources (Kane & McVay, 2012; Kopp & D’Mello, 2016; Smallwood & Schooler, 2006; Smallwood, 2013).

However, an opposite effect of difficulty has been reported for more complex tasks. In the context of reading, MW has been found to be more frequent when reading a difficult text compared to an easier text (Feng et al., 2013; Mills, D’Mello, & Kopp, 2015). In these studies, difficulty was manipulated via textual features such as syntactic complexity and the use of
unfamiliar terms. These features target the text base level, but ultimately influence deeper levels of text comprehension by impeding the construction of a situation model (Zwaan & Radvansky, 1998). When the situation model is impaired, it becomes more difficult to suppress self-generated thoughts and feelings, leading to an increase in MW (Feng et al., 2013; Smallwood, 2011).

Instead of targeting difficulty at the text base level, it is also possible to vary difficulty at the surface level, without changing the textual content. For example, perceptual difficulty (also known as disfluency) can be increased by changing the typeface of a text to one that is more difficult to read (e.g., from Arial to Comic Sans) (see Alter & Oppenheimer, 2009 for an extensive review). Several studies have shown that disfluency can have a positive effect on memory retention in list learning, suggesting that information that is more difficult to decode is encoded better on a surface level (Diemand-Yauman, Oppenheimer, & Vaughan, 2011). The additional cognitive burden created by disfluency can thus lead to a desirable outcome, namely deeper processing and better retention.

When it comes to reading, however, researchers have failed to find a consistently significant effect of disfluency on text comprehension (Eitel, Kühl, Scheiter, & Gerjets, 2014; Eitel & Kühl, 2016; Lehmann, Goussios, & Seufert, 2016; Rummer, Schwegge, & Schwede, 2016; Strukelj, Scheiter, Nyström, & Holmqvist, 2016). The incongruence between these findings and those for tasks like list learning suggests that disfluency only affects surface level learning (e.g., list retention) but not the construction of the situation model (e.g., text comprehension).

Does this mean that disfluency does not affect text comprehension at all? We argue that disfluency might indirectly affect comprehension by reducing MW. Specifically, the increased
surface level processing incurred when reading a disfluent text should leave fewer attentional resources available for MW, which in turn should have a positive effect on comprehension.

In line with this, we test two hypotheses on the relationship between perceptual disfluency, MW and text comprehension. First, consistent with studies showing reduced MW for tasks that require more attentional resources (but do not impede the construction of a mental model), we predict that an increase in perceptual disfluency should reduce MW. Second, given the preponderance of null effects in the literature (as noted above), it is unlikely that we will find a direct effect of perceptual disfluency on text comprehension. However, we expect that reduced MW attributed to disfluency should be related to improved text comprehension, suggesting that MW mediates the relationship between perceptual disfluency and comprehension. By analyzing the influence of disfluency on MW, we hope to provide an explanation for the puzzling lack of effect of disfluency on text comprehension.

2. Methods

2.1 Participants
A total of 207 Amazon Mechanical Turk (AMT) workers (U.S. residents only) completed this experiment. Participation was voluntary and participants received $2 in compensation. AMT can be used to collect reliable and valid experimental data (Mason & Suri, 2012), but in contrast with a lab study, experimenters have less control over the experimental settings, and participants’ age and education level may vary more than when sampling from a student population. However, given that online reading and learning is ubiquitous nowadays, sampling from a heterogeneous
population in a less controlled setting increases the ecological validity of the study and the authenticity of the learning experience.

Sample size was determined based on the minimum detectable effect size (MDES) for the main effect of disfluency on MW. An MDES calculation (Raudenbush, 2011) using two-tailed alpha of .05 and an observable power of .8 suggested that a total sample size of around 205 participants is necessary to detect an effect of 0.4 sigma (Cohen’s $d$), which is within the small-to-medium range. A large sample was also needed for the mediation analyses.

### 2.2 Design

The experiment utilized a between-subjects design. Participants read one of two texts in either Arial for the fluent condition, or *Comic Sans* for the disfluent condition (Figure 1; choice of typeface based on Diemand-Yauman et al., 2011). Assignment of condition was random, and text assignment was counterbalanced across participants.
2.3 Materials

2.3.1 Texts

Two texts on scientific research methods were taken from the electronic textbook that accompanies the educational game Operation ARA! (Halpern et al., 2012). These texts have been used in previous online reading studies (Mills et al., 2015; Phillips, Mills, D’Mello, & Risko, 2016). Research methods topics were used because the texts were educational, relatively unfamiliar to the average reader, and useful to a diverse population.
The text on dependent variables was 104 sentences long (1490 words), and the text on causal inference was 108 sentences long (1491 words). Both texts were at a moderate 9th grade level in terms of textual difficulty on the Flesch-Kincaid scale (Klare, 1974). Each text was presented one sentence at the time, and participants used the space bar to move to the next sentence. They could not move back to a previously read sentence.

2.3.2 Subjective perceptions

Participants completed a five-item questionnaire (Phillips et al., 2016) about their subjective experience after reading. The questionnaire measured effort (“I put a lot of effort into this”), interest (“I would describe this activity as very interesting”), and value (“I believe doing this activity could be beneficial to me”) to ensure that motivation was equivalent across conditions. Perceived difficulty (“I believe the reading level of the text was very difficult”) and competence (“I think I understood this text very well”) were also assessed to test whether the disfluency was consciously perceived. Each of these items was rated on a 6-point scale from (1) strongly disagree to (6) strongly agree.

2.3.3 Mind wandering probes

Participants were instructed to report mind wandering by responding to auditory thought probes (a beep) throughout reading. A standard description of mind wandering (based on Smallwood & Schooler, 2006) was provided before the reading task: “Sometimes when you are reading, you may suddenly realize that you are not thinking about what it is that you are reading. We call this “zoning out” about thoughts unrelated to the content of what it is we are reading.” Participants were instructed to indicate whether they were or we not mind wandering at the time of the probe.
by pressing the “y” or “n” key, respectively. Probes were placed on 9 pseudo-random pages throughout each text, and would never occur within the first or last 10 sentences, or within five sentences of each other. Probes were triggered when the participant pressed the space bar to move on to the next sentence, so per sentence reading times were not influenced by the probe responses.

2.3.4 Comprehension assessment

Comprehension was assessed on two levels: text level questions focused on factual or surface level characteristics of the text (e.g., “the passage says people who ___ do not fall for unsupported claims?”), while inference level questions required participants to draw inferences or apply their knowledge to a novel example (e.g., “[In this novel example], depression is the ___ variable, and art therapy is the ___ variable”). Both question types used a four-alternative multiple-choice format.

Before the reading phase, participants completed a pre-test about research methods. This test only included inference level questions because surface level questions cannot be answered without having read the text. Depending on the text, this test consisted of six questions about dependent variables or four about causal claims. After reading the target text, participants completed a post-test, which consisted of 12 new items for the dependent variable text (six inference level questions, six text level questions), or 12 new items for the causal claims text (three inference level, nine text level). The number of questions differed across texts due to the availability of validated items.
2.4 Procedure

Participants received a brief description of the study and were given the option to not volunteer before providing electronic consent. Participants then completed the pre-test questions. Next, they received instructions on how to respond to the MW probes, after which they began the reading task (which included the MW probes). After reading the text, participants completed the subjective perception questionnaire and comprehension assessment. On completion, they were fully debriefed.

2.5 Data Treatment

Three participants (1.4%) were removed due to noncompliance (reading times under 1.5 minutes; average reading time was 5.3 minutes ($SD = 2.1$)). All dependent variables were $z$-score standardized per text for statistical analyses (unless otherwise noted); unstandardized data are reported for descriptive purposes.

3. Results

3.1 Subjective perceptions

The fluency manipulation did not lead to significant (at two-tailed $p < .05$ for this and all subsequent analyses) differences in perceived difficulty (fluent: $M = 2.29$, $SD = 1.26$, disfluent: $M = 2.09$, $SD = 1.13$), effort (fluent: $M = 5.16$, $SD = .94$, disfluent: $M = 5.27$, $SD = .91$) or self-rated competence (fluent: $M = 4.41$, $SD = 1.17$, disfluent: $M = 4.42$, $SD = .99$), nor did it affect interest in (fluent: $M = 4.10$, $SD = 1.42$, disfluent: $M = 4.20$, $SD = 1.40$) or value (fluent: $M = 4.02$, $SD = 1.50$, disfluent: $M = 4.05$, $SD = 1.30$) of the activity. These results indicate that
fluency did not affect the participants’ subjective perceptions of the reading task, which is what 
was expected.

3.2 Mind wandering
We hypothesized that disfluency would lead to lower MW. Due to the non-normal distribution of 
standardized MW reports, we used a non-parametric test to analyze these data. A Mann-Whitney 
U-test revealed that the disfluent condition elicited significantly less MW than the fluent 
condition (fluent: $M = 27.8\%$, $SD = 28.4\%$, disfluent: $M = 21.0\%$, $SD = 28.6\%$, $U = 4204.5$, $p =
.017$, $d = -.34$ sigma). We also conducted a Poisson regression on the raw MW counts as an 
additional confirmatory analysis, which yielded similar results ($p = .017$, null deviance = 616.25, 
residual deviance = 600.00, controlling for text). On average, participants mind wandered 6.8% 
less while reading a text in a disfluent typeface, which is consistent with our predictions.

3.3 Comprehension
We observed a trend (albeit non-significant) suggesting that text level comprehension scores 
were higher for disfluent text (fluent: $M = 70.6\%$, $SD = 23.7\%$, disfluent: $M = 75.5\%$, $SD =
20.4\%$), $F (1, 202) = 2.28$, $p = .133$, $d = .21$ sigma. Inference level comprehension scores did not 
differ significantly between conditions (fluent: $M = 46.4\%$, $SD = 23.7\%$, disfluent $M = 49.3\%$, 
$SD = 25.8\%$; $F (1, 202) = .60$, $p = .440$, $d = .11$ sigma.

3.4 Effect of mind wandering on comprehension
We tested whether the relationship between disfluency and comprehension was mediated by 
MW. Note that according to contemporary mediation procedures, it is not necessary to observe a
significant direct effect of disfluency on comprehension to establish an indirect effect through MW (see: Zhao, Lynch Jr., & Chen, 2010 for a discussion). Indirect effects were computed using the ‘mediation’ package in R (Tingley, Yamamoto, Hirose, Keele, & Imai, 2014). We specified two models: a mediator model (Poisson regression of MW counts on disfluency) and an outcome variable model (linear regression of comprehension score on disfluency and MW). Both models used non-normalized MW counts, but text was added as a covariate. To control for the fact that longer reading times and prior knowledge were related to comprehension, pre-test scores and reading times were added as covariates to the appropriate outcome variable models. We then obtained causal estimates for the indirect effect of MW over 10,000 quasi-Bayesian Monte Carlo simulations. We found that the relationship between disfluency and text and inference level comprehension was indeed mediated by MW (Table 1), which supports the idea that disfluency positively affects comprehension by reducing MW.

|                  | Mean | Lower CI | Upper CI | p-value |
|------------------|------|![](images/0_15_0_15.png) | ![](images/0_15_0_15.png) | ![](images/0_15_0_15.png) | ![](images/0_15_0_15.png) |
| Text level       | .0594| .0097    | .1251    | .01     |
| Inference level  | .0411| .0029    | .0966    | .03     |

*Note: Reported CI’s are 95% confidence intervals.*

An important assumption in mediation analysis is that the relationships between condition, mediator and outcome are not confounded by other variables. MW was not significantly correlated with reading time (Spearman’s $\rho = -.07; p = .30$) or prior knowledge (Spearman’s $\rho = -.09; p = .19$). Both reading time and pre-test scores were correlated with text level comprehension ($r = .25, p < .001$ and $r = .16, p = .019$, respectively). Inference level comprehension was positively correlated with prior knowledge (i.e., pre-test scores, $r = .21, p = .003$) but not reading time ($r = .016, p = .816$). We therefore included covariates in the appropriate models (reading time and prior knowledge for text level comprehension, prior knowledge for inference level comprehension), which is a common way to address this issue (Preacher, 2015). We would nevertheless like to point out that the same analyses without covariates yield similar results (text level: estimate = .0650, lower CI = .0103, upper CI = .1372, $p = .02$; inference level: estimate = .0434, lower CI = .0040, upper CI = .1024, $p = .02$).
4. Discussion

The aim of this study was to investigate the effect of perceptual processing difficulty on mind wandering during text comprehension. We hypothesized that the added perceptual processing required for reading disfluent text leaves fewer cognitive resources available for MW. As hypothesized, we found that MW rates were lower for perceptually disfluent texts with identical content as the fluent texts. Furthermore, we hypothesized that a decrease in MW due to disfluency would affect text comprehension. Our results indicate that MW mediated the relationship between disfluency and comprehension, suggesting that disfluency has an indirect positive effect on comprehension by increasing attentional resources directed to the reading task. Simply put, perceptual disfluency acts as a “desirable difficulty” (cf. Diemand-Yauman et al., 2011) by reducing MW during reading.

The fact that we did not observe a significant direct effect of disfluency on text comprehension is in line with other recent findings (Eitel et al., 2014; Eitel & Kühl, 2016; Lehmann et al., 2016; Rummer et al., 2016; Strukelj et al., 2016). However, we have shown that disfluency has an indirect effect on text comprehension by reducing MW, thereby elucidating one mechanism by which disfluency influences the reading process. An open question is why studies (including ours) fail to observe a direct effect of disfluency on comprehension. One possibility is that although the processing load engendered by disfluency can reduce MW, disfluency itself does not contribute to the construction of a mental model of the text. It can therefore be considered to impose an extraneous cognitive load (see Paas, Renkl, & Sweller, 2004), which might act as a competing mediator, thereby precluding a direct effect.
Recent work has also suggested that learner characteristics such as *need for cognition* (Cacioppo & Petty, 1982) might moderate disfluency effects (Kühl, Eitel, Damnik, & Körndle, 2014; Kühl, Eitel, Scheiter, & Gerjets, 2014). A participant’s willingness to put effort into learning is likely to affect whether s/he benefits from the increase in processing load. Future research could further explore the effect of individual differences on the relationship between disfluency, MW, and comprehension.

It is important to note that participants did not subjectively perceive reading disfluent text as more difficult or effortful, nor did it affect their ratings of self-competence. This suggests that (as intended) the disfluency manipulation was subtle enough to not be consciously appraised as being a hindrance to comprehension. Indeed, alternate content-oriented manipulations of textual difficulty (as opposed to content-free manipulations of processing difficulty) are consciously appraised as such and have been shown to increase MW (Feng et al., 2013; Mills et al., 2015). Our study suggests that textual difficulty and perceptual disfluency have opposite effects on MW, supporting the idea that both influence cognitive processing in different ways (Alter & Oppenheimer, 2009b; Diemand-Yauman et al., 2011). Together, these findings indicate that disfluency can reduce MW without participants being aware of the extra processing cost and can lead to opposite effects than more content-oriented manipulations of text difficulty.

It is also presently unknown whether disfluency interacts with other types of difficulty. For instance, performance might degrade if the cognitive load imposed by disfluency and other task demands (e.g., textual difficulty) is too high (Paas et al., 2004). Further research, including

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2 Overall, self-reported difficulty did not significantly predict mind wandering (Spearman’s *rho* = .069, *p* = .328). There was a trend suggesting that (as expected) self-reported difficulty is negatively related to text-level comprehension (*r* = -.133, *p* = .057) but not inference-level comprehension (*r* = -.030, *p* = .668).
replications with different texts and/or tasks, is necessary to determine the boundary conditions of the effect of disfluency on MW and comprehension.

Like all, our study is not without limitations. These findings—and in fact all studies that rely on self-reported MW—rest upon the assumption that participants report MW accurately and honestly. Disfluency tends to be associated with less self-disclosure of unfavorable information (Alter & Oppenheimer, 2009a), so the lower MW rates for the disfluent condition might be associated with a decrease in participant’s willingness to admit to MW. However, this alternate explanation does not effectively explain the negative relationship between (admitting to) MW and comprehension. Nevertheless, this issue awaits future research with more objective measures of MW (Faber, Bixler, & D’Mello, in review).

In conclusion, we have shown that attention is one of the mechanisms affected by disfluency during reading. Although we acknowledge that disfluency might also affect other cognitive mechanisms, we argue that this finding is important to the fields of cognitive and educational psychology because it suggests that a simple change in typeface can reduce mind wandering, which is negatively associated with text comprehension. This finding is therefore an important step towards a better understanding of how text characteristics and attention interact during reading comprehension.
References


Faber, M., Bixler, R., & D’Mello, S. (in review). An Automated Behavioral Measure of Mind Wandering Rates during Computerized Reading.


