Received: 27 February 2020 | Revised: 1 March 2021 | Accepted: 2 March 2021

DOI: 10.1111/lnc3.12412

ARTICLE

WILEY

Mind wandering during reading: An interdisciplinary and integrative review of psychological, computing, and intervention research and theory

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Funding information
NSF, Grant/Award Numbers: DRL 1235958, DRL 1920510, IIS 15230911

Abstract

A large proportion of thoughts are internally generated. Of these, mind wandering—when attention shifts away from the current activity to an *internal* stream of thought—is frequent during reading and is negatively related to comprehension outcomes. Our goal is to review research on mind wandering *during reading* with an interdisciplinary and integrative lens that spans the cognitive, behavioural, computing and intervention sciences. We begin with theoretical developments on mind wandering, both in general and in the context of reading. Next, we discuss psychological research on how the text, context and reader interact to influence mind wandering and on associations between mind wandering and reading outcomes. We integrate the findings in a (working) theoretical account of mind wandering during reading. We then turn to computational models of mind wandering, including a short tutorial with examples on how to use machine learning to construct these models. Finally, we discuss emerging intervention research aimed at proactively reducing the occurrence of mind wandering or mitigating its effects. We conclude with open questions and directions for future research.

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1 | INTRODUCTION

While reading this article, please keep track when you catch yourself zoning out—when your thoughts shifted away from the text to something else altogether:

If you follow this instruction, you will likely report a few cases of zone outs, a colloquial term for mind wandering. Research suggests that mind wandering occurs with remarkable frequency in everyday life, with estimates ranging from 30% to 50% (Killingsworth & Gilbert, 2010; Klinger & Cox, 1987; Mills et al., 2018). It has been suggested that the ability to escape the external world through mind wandering can be beneficial, especially for creative thinking and future planning (Baird et al., 2012; Mooneyham & Schooler, 2013; but also see Storm & Bui, 2016). However, it is consistently associated with performance decrements on numerous cognitive tasks (D'Mello, 2019), more so for more complex tasks (Randall et al., 2019) like reading, where it occurs roughly 20%–30% of the time, and is consistently negatively associated with comprehension outcomes.

Mind wandering is an important factor in scientific studies of reading and efforts to improve reading outcomes. In the past decade, research in the psychological sciences has made remarkable strides in expanding our understanding of mind wandering across a variety of tasks including reading comprehension. However, this research has yet to meaningfully influence the text and discourse communities.[1] In addition, in a review of the major theories of reading comprehension, McNamara and Magliano (2009) note that all theories assume that readers focus attention on goal-relevant content (i.e., a discourse focus). A notable omission is that these theories do not address cases where attentional focus is on thoughts unrelated to the textual content as in the case of mind wandering. The relatively high frequency of mind wandering during reading suggests that it might be an important overlooked phenomenon in reading comprehension research. Thus, one goal of this paper is to provide an accessible review to encourage researchers to incorporate mind wandering and related attentional processes into their theories and empirical investigations. We focus on reading for understanding (Snow, 2002), or the task of comprehending expository, informational and narrative text by fluent readers. To keep scope manageable, we highlight and summarize some of the key research areas with the hope that this will pique readers' interests and encourage them to explore each area more deeply. We also provide a working theoretical account centred around mind wandering during reading in an effort to integrate emerging theories and empirical findings.

In addition to emerging research from the psychological sciences, parallel research from the computational sciences has the potential to transform research and practice on mind wandering during reading. Specifically, the fields of machine learning and human–computer interaction (HCI) have developed technologies that can automatically measure mind wandering from a range of behavioural signals. Integrating these measures in 'attention-aware' technologies (Roda & Thomas, 2006), which automatically deliver interventions to mitigate the occurrence and effects of mind wandering (Mills et al., in press) can revolutionize attempts to improve reading comprehension. Because these methods and techniques are outside of the purview of most reading comprehension researchers, a second goal of this paper is to provide an accessible introduction to relevant computational and intervention research. At the very least, it should provide reading researchers with a common language to engage in cross-disciplinary dialogues with computer scientists. With these dual goals in mind, we begin with a broad background on mind wandering including, but not exclusive to, reading research.

2 | BACKGROUND ON MIND WANDERING

2.1 | What is mind wandering?

Over the last two decades, mind wandering has variously been defined as stimulus-independent thought, task-unrelated thought, stimulus independent and task-unrelated thought, and unintentional task-unrelated thought (Klinger & Cox, 1987; Seli, Kane, Smallwood, et al., 2018; Smallwood & Schooler, 2015). Definitional conflict is not entirely surprising given the multiplicity of views about how mind wandering should be defined and operationalized. Seli et al. (2016), for example, urge researchers to consider multiple types of mind wandering (i.e., task-unrelated thought) based on intentionality, whereas others question the idea that mind wandering can even occur intentionally; for a discussion see Irving (2016) and Murray and Krasich (2020). Christoff et al. (2016) have argued that content-based definitions, such as task-unrelated thought, are insufficient because they do not capture the dynamics of how thoughts unfold over time. They suggest instead that free movement in thought from one mental state to the next with relatively few constraints is an essential property of mind wandering. Whereas this approach captures an intuitive sense of the term mind wandering (Irving et al., 2020), it does not seamlessly align with the above operational definitions (Seli, Kane, Metzinger, et al., 2018).

To address these conflicts and plurality of dimensions Seli, Kane, Smallwood, et al. (2018) proposed that the field should abandon attempts to find a single definition and instead consider mind wandering to be a 'family' of heterogeneous overlapping constructs with graded membership. In this view, thoughts are considered part of the family based on the overlap with one or more characteristics (i.e., task relatedness, stimulus independence, intentionality). This approach bypasses the need to define mind wandering based on a single (or set of), necessary and sufficient characteristics, which is beneficial for connecting researchers studying similar phenomena. However, critics (Christoff et al., 2018) argue that this approach makes it difficult to delineate what is and *is not* mind wandering because it encompasses almost all types of internally generated thoughts (e.g., rumination, goal-directed thought, obsessive thought).

These definitional debates (see Christoff et al., 2018; Seli, Kane, Metzinger, et al., 2018) notwithstanding, over 90% of studies (Mills et al., 2018) operationalize mind wandering as *task-unrelated thought*—thoughts that have shifted away from the current task to an *internal* stream of thought. We adopt this definition in our review of the literature, but later provide a more nuanced conceptualization of mind wandering specific to reading comprehension.

2.2 | Why does the mind wander?

There are two primary accounts of why mind wandering arises. The first account, the *executive resource* hypothesis, suggests that mind wandering arises when there is an excess amount of unused resources that can then be co-opted by task-unrelated thoughts (Smallwood & Schooler, 2006). In contrast, the *executive control failures* × *current concern* hypothesis proposes that mind wandering will arise when cognitive control fails to prevent task-unrelated intrusions (Kane & McVay, 2012; McVay & Kane, 2010). Although these two accounts were initially the subject of much debate, Smallwood (2013) suggested they are not mutually exclusive but rather a matter of timing. In his *process-occurrence* framework, a mind wandering episode is *initiated* due to a control failure, but is then *maintained* when unused executive resources are available to support an internal focus on the mind wandering episode.

Individual differences also play a role in the propensity to mind wander. *Resource theories* combine individual attributes of motivation, executive function, etc. with task characteristics (mainly task demands) to predict how attention will be allocated to a task (Randall et al., 2019). The general idea is that mind wandering will be more likely for *resource-intensive* tasks where task demands (determined as a function of individual abilities and task difficulty) are either too low or too high because performance is minimally affected by attention and cognitive effort compared to *resource-sensitive tasks* where task demands are more moderate. Finally, the *context regulation* (Smallwood & Andrews-Hanna, 2013) and *cognitive flexibility* (Rummel & Boywitt, 2014) hypotheses highlight the malleability of executive resources as a function of context and working-memory capacity, respectively, but, have yet to be adequately tested (Robison et al., 2020).

2.3 | How is mind wandering measured?

Mind wandering is inherently an internal, conscious, process (Smallwood & Schooler, 2015). Hence, experience sampling—collecting self-reports regarding a person's ongoing experience (Csikszentmihalyi & Larson, 1987)—is the most common method of measuring it. The *probe-caught* method adopts an online thought sampling approach (Smallwood & Schooler, 2006; Weinstein, 2018). For example, readers would be periodically (e.g., every 2 min) interrupted by an auditory or visual probe, which would ask whether they were currently thinking about the text or something unrelated. In contrast, the *self-caught* method requires readers to indicate (e.g., via a key press) the moment they become aware that their minds were no longer focused on the text (Schooler et al., 2011). Two less common methods include retrospective self-reports, which occur after reading, or open-ended methods where readers report their experiences or thought contents in their own words (Smallwood & Schooler, 2015). Table 1 provides sample probe-caught instructions to participants in a reading study (Kopp et al., 2015). As these instructions illustrate, inferencing and elaborative processing that goes beyond the text (Graesser et al., 1994) are not considered zone outs.

A strength of the probe-caught method is that people need not be aware of their own thoughts (i.e., meta-awareness) during reading, but it is subject to demand characteristics. Further, the probes may not 'catch' all mind wandering episodes due to limits on the timing and number of probes. The self-caught method conveniently avoids these issues and is more naturalistic. However, mind wandering can occur without meta-awareness (e.g., suddenly realizing that your eyes have moved across multiple paragraphs of text but you have no idea what you just read), so people may not even be aware that their minds have wandered (Schooler et al., 2011). Varao-Sousa and Kingstone (2019) demonstrated that the artificial probing method does not disrupt the more naturalistic self-caught method, so both can be used at the same time.

Research has indicated that both (probe- and self-caught) methods produce reliable measures (Schubert et al., 2019; Varao-Sousa & Kingstone, 2019) within the limits of self-reporting. For example, mind wandering measures are internally consistent in that within-subject correlations are high (Faber et al., 2018a), they are reliably linked to predictable patterns in physiology (Smallwood et al., 2004), pupillometry (Franklin et al., 2013), eye gaze (Reichle et al., 2010), and they demonstrate predictive validity via negative associations with task performance (Randall et al., 2014). As expected, mind wandering rates can vary as a function of

TABLE 1 Instructions for reporting self-caught mind wandering (Kopp et al., 2015); sentence markers (S1, S2, etc.) added for illustration purposes

S1: Your primary task is to read the text in order to take a short test after reading. S2: At some points during reading, you may realize that you have no idea what you just read. S3. Not only were you not thinking about what you are actually reading, you were thinking about something else altogether. S4. This is called 'zoning out'.
S5. If you catch yourself zoning out at any time during reading, please indicate what you are thinking about at that moment during reading.
S6. When zoning out:
S6a. If you are thinking about the task itself (e.g., how many pages are there left to read, this text is very interesting) or how the task is making you feel (e.g., curious, annoyed) but not the actual content of the text, please press the key that is labelled 'task".OR S6b. If you are thinking about anything else besides the task (e.g., what you ate for dinner last night, what you will be doing this weekend) please press the key that is labelled 'other".
S7. Please familiarize yourself with where these two keys on the keyboard now so that you will know their location when you begin reading.
S8. Please be as honest as possible about reporting zoning out. S9. It is perfectly natural to zone out while reading. S10. Responding that you were zoning out will in no way affect your scores on the test or your progress in this study, so please be completely honest with your reports. S11. If you have any questions about what you are supposed to do, please ask the experimenter now."

Notes. These instructions clarify that the primary task is reading (S1) and encourage participants to monitor their ongoing comprehension of the text (rather than their thoughts) (S2). The critical phrase (S3) clarifies that only thoughts that are completely unrelated to the text should be classified as zone-outs. After defining zone-outs (S4), the reader is instructed to report self-caught instances of zone-outs (first part of S5), which would typically be followed by instructions[8] on how to report zone-outs (e.g., "press the Z key"). Here, readers were instructed to distinguish between task-related interferences (TRIs; S6a) and task-unrelated thoughts (TUTs; S6b). The readers are then provided instructions on how to report zone-outs (S7) and are encouraged to be honest with their reporting (S8–S10). Finally, there is an option to obtain additional clarification (S11).

methodological choices. For example, Weinstein et al. (2018) found that mind wandering was reported more frequently when probes had a mind wandering-positive frame ('my mind was on something other than the text') versus a task-positive frame ('my mind was on the text'). Whereas other methodological artefacts such as probe spacing (Seli et al., 2013) and probe-response options (Seli, Beaty, et al., 2018) can influence mind wandering responses, Schubert et al. (2019) suggest that these factors do not influence the reliability and generalizability of corresponding studies. Thus, if carefully administered, self-reports remain the most viable way to measure an internal phenomenon such as mind wandering.

2.4 | What are the neural correlates of mind wandering?

Mind wandering is sometimes thought to be an extension of the human resting state due to its strong association with the Default Network (DN; Mason et al., 2007), which characterizes human brains 'at rest' (i.e., given no explicit task) using functional magnetic resonance imaging (fMRI) (Buckner et al., 2008; Gusnard et al., 2001; Raichle et al., 2001). However, more recent work suggests that the DN is temporally coupled with the frontoparietal control network (FPCN) during mind wandering (Christoff et al., 2009; Fox et al., 2015). This DN–FPCN coupling is also observed in cognitive processes that comprise the dominant themes of mind wandering content (Andrews-Hanna et al., 2013; Fox et al., 2013; Klinger, 2009), such as autobiographical memory (Spreng et al., 2009), mentalizing (Spiers & Maguire, 2006) and planning (Spreng et al., 2010). A recent study found that reduced connectivity between the DN and the visual system may explain the tendency to mind wander during reading (Zhang et al., 2019). However, Smallwood et al. (2013) suggested that differences in intrinsic connectivity (i.e., 'baseline' brain connectivity measured at rest) in two DN-midline hubs—the posterior cingulate cortex and the anterior medial prefrontal cortex—were implicated in both maintaining focus during reading but impaired comprehension afterwards, highlighting its flexibility in supporting different cognitive processes.

Mind wandering can also be measured from electroencephalography (EEG) as demonstrated by Zhou et al. (2020) who used spectral similarity analysis to compare EEG activity during reading and at rest. They developed a 'baseline' measure for each reader by estimating spectral characteristics from resting state EEG. On a moment-by-moment basis, participants' spectral EEG data during a reading task was correlated with their baseline measure; the assumption being that EEG signals would be more similar to the baseline measure when readers are mind wandering compared to actively reading. This measure of inattention negatively predicted reading comprehension, providing some evidence for this claim.

Having covered some of the background of mind wandering in general, we now review cognitive and behavioural research on mind wandering during reading.

3 | COGNITIVE AND BEHAVIOURAL RESEARCH

We begin by examining mind wandering from the perspective of the text, task context and the reader (Snow, 2002), along with possible interactive effects. Next, we discuss influences of mind wandering on text processing, comprehension and learning outcomes.

3.1 | What influences mind wandering during reading?

3.1.1 | The text

Perhaps the most widely studied component of the text involves manipulations of text difficulty. Such studies typically contrast easy and difficult versions of the same text, achieved by manipulating word and sentence length (Feng et al., 2013; Mills et al., 2015), amongst other factors. Studies using simple cognitive tasks, such as the sustained attention response task (SART), which requires participants to suppress responses to an infrequent target interspersed among frequent non-targets, report more mind wandering for easy task conditions, which is attributable to availability of executive resources (Smallwood & Schooler, 2006). In contrast, Feng et al. (2013) suggested that mind wandering would be more frequent while reading difficult texts because readers will have more difficulty constructing a mental model and will experience more executive control failures. This finding was confirmed by Feng et al. (2013) and subsequently replicated (Mills et al., 2013, 2015; Soemer et al., 2019; Soemer & Schiefele, 2019).

This seeming discrepancy in findings—namely that both lower and higher task demands can increase mind wandering—has been studied in more detail in non-reading contexts. Randall et al. (2019) found that task demands had a nonlinear effect on mind wandering in a math problem-solving task in that participants were more likely to report mind wandering in both low- and high-demand tasks in comparison to a moderately demanding task. This is also consistent with Xu and Metcalfe (2016) who found that participants (while learning English–Spanish word pairs) reported mind wandering more often during an easy or difficult version of the task compared to a moderately difficult version, or what they referred to as the 'region of proximal learning'. These non-linear effects of manipulated difficulty are consistent with the resource theory view (Randall et al., 2019) that tasks on either end of the demand spectrum (extremely high or low) are resource-insensitive, whereby exerting more effort is unlikely to influence performance, and thus are likely to promote mind wandering.

3.1.2 | The task context

Studies have explored how aspects of the reading context, such as how the text is displayed and reading instructions, influence mind wandering. Whereas the above studies that found that textual difficulty increased mind wandering used both sentence-level (Feng et al., 2013) as well as paragraph-level presentation (Mills et al., 2015), Forrin et al. (2019) could only replicate this finding for sentence-by-sentence text presentation. They hypothesized that because difficult texts have longer sentences, there is more content displayed on the screen (compared to easy texts) for sentence-by-sentence presentation. They found that readers consistently rated texts presented with longer section lengths as being more difficult (even though content was identical) and mind wandered more when reading these texts, which they deemed the *section-length* effect. Interestingly, the effect was only observed in within-subjects designs; the effect disappears in between-subject designs (Forrin et al., 2018), suggesting that the effect is in part driven by evaluative context of the task (i.e., a within-subjects but not between-subjects design affords comparing shorter vs. longer sections). Nevertheless, the combined pattern of results supports the notion that text difficulty, both actual and perceived, increases mind wandering.

Other studies have explored how subtle changes to the reading context can influence mind wandering. Faber et al. (2017) reported lower mind wandering when participants read a text with a less fluent typeface (i.e., grey Comic Sans vs. black Arial), presumably because this consumed more resources during encoding without exceeding readers' abilities. This is distinct from textual difficulty, which is a content manipulation, whereas the fluency manipulation is merely perceptual. Kopp and D'Mello (2016) found more mind wandering when a text was presented orally—akin to an audiobook—compared to reading with or without audio narration (see Varao-Sousa et al. [2013] for a similar finding). They attributed this finding to an unoccupied visual channel—and thereby more available resources for mind wandering—in the audio-only condition. Similarly, Phillips et al. (2016) observed more mind wandering when participants re-read a text compared to their own first read and to participants who only read it once, presumably because re-reading consumed fewer resources (among other factors); Martin et al. (2018) replicated this finding in the context of re-watching lectures.

3.1.3 | The reader

With respect to individual differences, both general—working memory capacity and attentional control (WMC-AC) (McVay & Kane, 2012; Robison & Unsworth, 2015; Unsworth & McMillan, 2013)—and situational factors—topic interest (Krawietz et al., 2012; Soemer et al., 2019;

Soemer & Schiefele, 2019; Unsworth & McMillan, 2013)—have emerged as strong negative predictors of mind wandering. Because WMC is related to attentional control, individuals high in WMC should be more successful in suppressing off-task thoughts. Similarly, high topic interest, a component of motivation, should help sustain attention while reading. Both WMC (Daneman & Carpenter, 1980; Daneman & Merikle, 1996) and topic interest (Ainley et al., 2002; Schiefele, 1999) have also been reliably associated with reading comprehension, and mind wandering *during* reading partly mediates this relationship (McVay & Kane, 2012; Soemer et al., 2019; Unsworth & McMillan, 2013). Thus, mind wandering might be a potent mechanism to explain two robust individual difference predictors of reading comprehension.

Mind wandering can also be increased by manipulating the mental state of the reader prior to reading. Kopp et al. (2015) found that directing attention towards current concerns (Klinger, 1987), such as short-term plans, resulted in significantly more mind wandering; Masicampo and Baumeister (2011) report a qualitatively similar finding. Fulmer et al. (2015) found that manipulating perceived interest through the provision of choice prior to reading influenced mind wandering in certain cases (see below), but Mills et al. (2015) found null effects for a consequence value manipulation (i.e., increasing/decreasing the value of comprehending a text) prior to reading.

3.1.4 | Interactive effects

A few studies have examined interactions among the text, task context and the reader, resulting in the following findings. First, reader variables such as interest moderates how often people mind wander under different task demands. Fulmer et al. (2015) found that perceived interest prior to reading buffered the effects of text difficulty in that there was no difficulty effect for the high interest texts, whereas mind wandering was higher for the easier texts when interest was low.[2] However, a subsequent study found no evidence of an interaction between consequence value (a utility-value motivational manipulation) and text difficulty on mind wandering (Mills et al., 2015). Second, texts will be more/less demanding for different people depending on their prior knowledge, reading fluency, working memory capacity and attentional control. Extant data, outside of reading, suggest that the relationship between task demands and mind wandering may be moderated by individual differences. For example, Xu and Metcalfe (2016) found that participants with higher prior knowledge (in Spanish) reported more mind wandering during the easier version of a word learning task compared to the more difficult versions, relative to those with lower prior knowledge. Similarly, Randall et al. (2019) also found that people with higher WMC/attentional control were less likely to mind wander as tasks demands increases. There is a general paucity of similar studies in reading contexts.

3.2 | How is mind wandering related to comprehension outcomes?

The idea of *decoupling*—attention is decoupled from the environment—has emerged as the primary mechanism by which mind wandering influences performance outcomes (Schooler et al., 2011). Multiple studies provide support for this account. In a word-by-word reading paradigm, for example, reading times are not sensitive to lexical features of words (perceptual decoupling) during mind wandering (Franklin et al., 2011). Similarly, readers who mind wander when critical details are presented in a text (e.g., the villain is wearing a hood) are less likely to make inferences later in the narrative (e.g., John is wearing a hood so he is the villain) (Smallwood, 2011). Mills et al. (2017) found that a lack of alignment between paragraph-level reading times and text difficulty on those paragraphs (termed cognitive decoupling) predicted mind wandering, even after accounting for overall reading times. They also found that cognitive coupling mediated the effects of mind wandering on reading comprehension, suggesting a possible mechanism.

The decoupling account would suggest a negative correlation among mind wandering and comprehension outcomes, which is supported by almost all studies. The more interesting question thereby pertains to the magnitude of the correlation. Accordingly, we extracted 21 effects from reading studies[3] reported in a meta-analysis on mind wandering and performance across a range of tasks (Randall et al., 2014) and combined them with 25 effects from our own lab[4] (D'Mello studies) in a mini meta-analysis (Goh et al., 2016). The weighted mean correlation under a random effects model r_+ ($k = 45$, $n = 2793$) was −0.31 ($p < 0.001$, 95% CI [−0.35, −0.26]), and the test of heterogeneity was significant, $Q(44) = 68.7$, $p = 0.01$ (see Figure 1 for a forest plot of the effects). The mean correlation for the Randall et al. (2014) effects was −0.11 higher ($r_+ = -0.39$, $p < 0.001$, 95% CI [−0.49, −0.29]) than our lab effects ($r_+ = -0.27$, $p < 0.001$, 95% CI [−0.31, −0.22]), which might be attributable to numerous factors including the subject populations, texts, task instructions and comprehension measures. A trim-and-fill analysis indicated six potential missing studies; adjusting for these resulted in an overall effect of −0.28 (95% CI [−0.33, −0.22], $k = 51$, $p < 0.001$). Thus, mind wandering explains approximately 7%–9% of the variance in reading comprehension outcomes.

Beyond correlational relationships, some studies suggest a causal role for mind wandering. Both Kopp et al. (2015) and Faber et al. (2017) found that mind wandering mediated the effect of current concerns and textual disfluency (manipulated variables), respectively, on comprehension outcomes. Similarly McVay and Kane (2012) reported that mind wandering mediated the influence of WMC/attentional control on comprehension outcomes. When combined with the above decoupling studies, there is tentative support for the following casual chain: Text/Task/Individual differences → Mind wandering → Decoupling → Comprehension outcomes.

In sum, we reviewed cognitive and behavioural research on mind wandering during reading. The research identified text difficulty, text presentation (e.g., section length, typeface), topic interest and working memory capacity (WMC) as the main variables that influence the occurrence of mind wandering during reading. A mini-meta analysis also indicated that mind wandering was consistently negatively correlated with reading comprehension outcomes, and there is evidence to suggest that mind wandering plays a mediating role, though evidence is limited to immediate comprehension of the text.[5] Future research should investigate more distal influences of mind wandering, including its effects on longer term retention and transfer and on investigating the causal chain connecting individual differences to comprehension outcomes.

4 | AN INTEGRATIVE (WORKING) THEORETICAL ACCOUNT OF MIND WANDERING DURING READING

Drawing on reading and non-reading studies of mind wandering, we provide a working theoretical account that aims to integrate theoretical and empirical research on the antecedents and consequences of mind wandering with a specific focus on reading (see Figure 2).

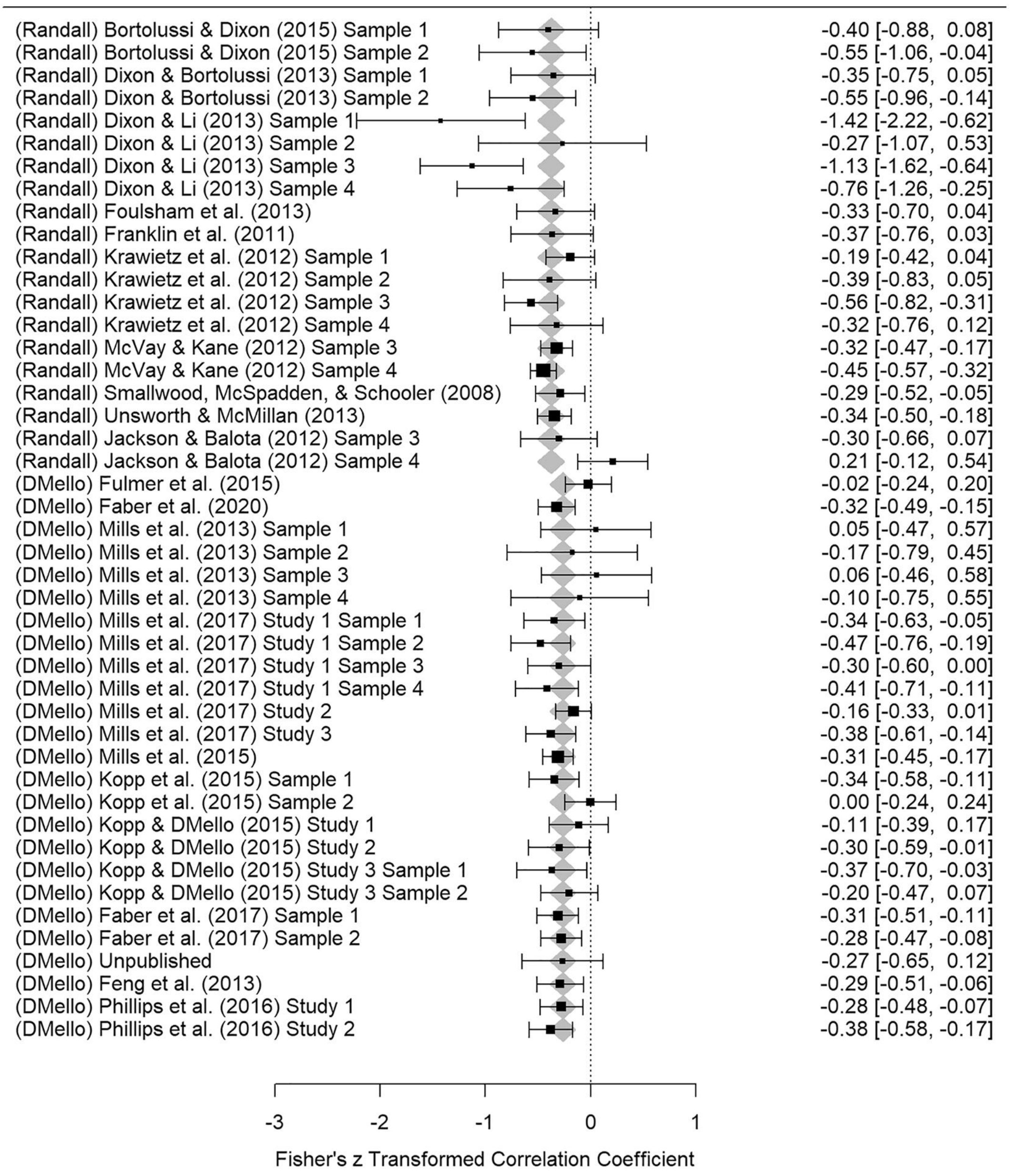

FIGURE 1 Forest plot of mini meta-analysis of correlations between mind wandering and reading comprehension outcomes

4.1 | Goal congruent versus incongruent thoughts

We suggest adopting a goal-oriented focus to determine what constitutes mind wandering as this may vary from task to task. Accordingly, we assume that the goal of reading is to construct a mental model of the text for immediate understanding (comprehension), for later retrieval (learning), or for some other purpose (application). Researchers have developed a number of

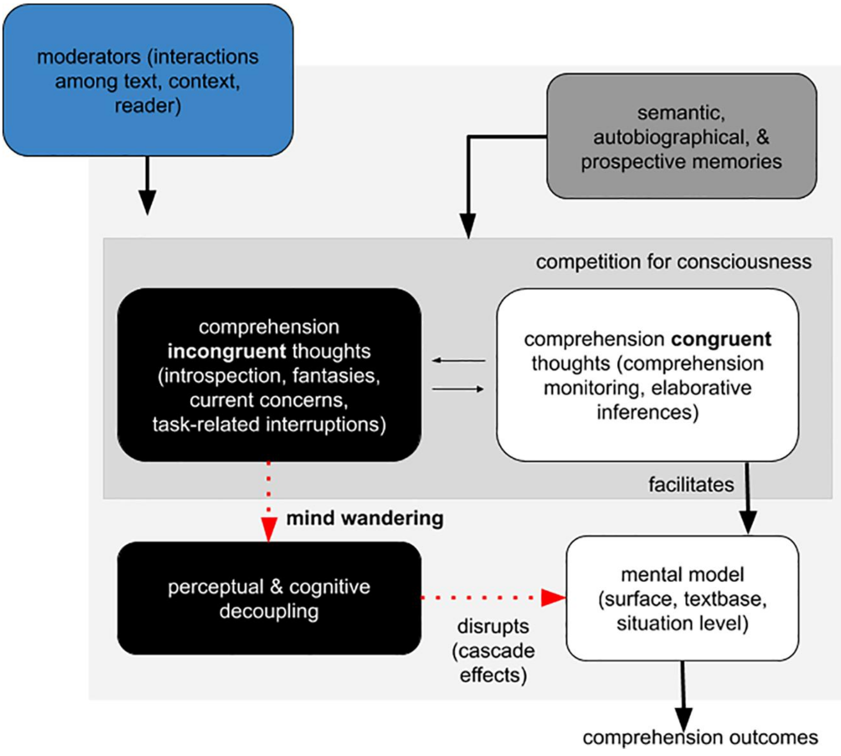

FIGURE 2 Integrative theoretical account of mind wandering during reading

theoretical models to describe how text representations (i.e., mental models) are constructed and maintained during reading; see McNamara and Magliano (2009) for a review.

The earliest and most complete of these models, the construction-integration (CI) model (Kintsch, 1988, 1998) posits that a construction phase first leads to activation of all relevant information without being constrained by any prior knowledge. This is followed by an integration phase (Garnham, 2021) when activation eventually settles by emphasizing concepts that are linked to other concepts in the text or in prior knowledge and de-emphasizing irrelevant or inconsistent concepts. The construction and integration processes result in the text being represented at multiple levels: surface level (i.e., memory for syntax and textual details), text base (i.e., text propositions) and importantly, the situation model, which incorporates inferences generated and knowledge activated to create a deeper understanding of the text (McCarthy & McNamara, 2021).

We refer to thoughts that support the basic processes of constructing, maintaining, or utilizing a mental model of the text as comprehension-congruent (CC) thoughts; here the goal of reading is comprehension. These thoughts can extend beyond the task and text, as in the case of an elaborative inference (Graesser et al., 1994; McNamara, 2021), but directly support the comprehension goal. In contrast, a comprehension incongruent (CI) thought does not facilitate the comprehension goal despite its possible relation to the task and text. For example, metacognitive reflecting on the level of comprehension would be a CC thought, but reflecting on how many pages are left to read (a task-related interference because the thought is superficially related to the task [e.g., task instructions] but not germane to the comprehension goal), or focusing on an irrelevant detail of the stimulus (e.g., the typeface) would be categorized as CI thoughts. For this reason, we think that CI thoughts offer a more precise conceptualization of mind wandering than task-unrelated thoughts during reading. Similarly, a stimulus-independent thought need not be mind wandering, for example, when a reader engages in elaborative processing that extends beyond the text (i.e., the stimulus) as this is highly germane to the comprehension goal (McNamara, 2021).

As we elaborate in Figure 2, CC and CI thoughts compete for conscious access (Smallwood, 2010), which is a limited resource because consciousness is serial and has limited capacity (Baars, 1993). CC thoughts claim the seat of consciousness to the extent that executive control is successful at suppressing CI thoughts (Kane & McVay, 2012). In contrast, the mind wanders when executive control fails (Kane & McVay, 2012) and when there are available executive resources to maintain focus on CI thoughts (Smallwood & Schooler, 2006); this is consistent with the process-occurrence account elaborated above (Smallwood, 2013). Importantly, the strength of the ongoing mental model influences mind wandering. Consistent with resource theories, when a reader struggles to construct a mental model, due to a lack of interest, prior knowledge, fatigue or other reason, this has an influence on executive control (Pessoa, 2009), which in turn, can increase the likelihood of CI thoughts (Randall et al., 2019). Conversely, CI thoughts are more likely to be suppressed when an engaged reader constructs a robust mental model which can be used to generate predictions of how the text will unfold (Kopp et al., 2016).

4.2 | Thought content, thought triggers and thought trains

An important claim of the account is that reading for understanding is rich in semantics and involves different thought content and dynamics compared to semantically impoverished tasks (e.g., lab-based working memory and attention tasks). The basic idea is that CI thoughts can be triggered by a variety of sources, which also prescribe thought content. Some well-understood sources include internal factors like feeling states (e.g., hunger pangs) and fantasies (e.g., 'What it would be like if there were a fire drill right now'), as well as external factors such as task-related interferences (e.g., 'how much longer?') or distractions (e.g., a door slammed) (Baird et al., 2011; Faber & D'Mello, 2018; Klinger, 1987; Stawarczyk et al., 2011). Sometimes the stimulus itself (Faber & D'Mello, 2018) can be a source of CI thoughts, for example, when the reader focuses on an irrelevant detail such as the typeface or other aspects of the presentation (e.g., 'These sentences are abnormally long').

Critically, and somewhat ironically, in the case of reading, memory retrieval triggered by text processing is a substantial source of CI thoughts. On the one hand, core reading processes, such as prior knowledge activation (McCarthy & McNamara, 2021; O'Brien et al., 1998) and elaborative inferencing (Graesser et al., 1994; McNamara, 2021), which rely on memory associations are essential to comprehension. On the other hand, the same processes can also yield irrelevant autobiographical (e.g., reading the word 'water' in a science text triggers a memory of the past weekend spent at the beach), prospective (e.g., reading 'water' leads to prospection about a need to buy sparkling water for dinner), and semantic (e.g., reading 'water' brings the chemical formula H_2O to mind) memories. Thus, the automaticity of memory retrieval is a double-edged sword because it supports both CC and CI thoughts.

To this point, Faber and D'Mello (2018) found that a large amount (44%) of mind wandering thoughts during reading (and similarly while watching a film) were related to episodic, semantic and other (unspecific) memories or to the stimulus itself.[6] They also found that more than 70% of autobiographical and semantic memory retrievals were triggered by the stimulus, compared to about 30% for prospective and introspective thoughts. For example, the trigger 'all the talk about water' from the text stimulus and the memory '[a] beach nearby me at home that I always go to' are related, because water and beach share associations like the sea and swimming. Further, latent semantic analysis (LSA)—a natural language processing technique that measures the semantic similarity of texts (Landauer & Dumais, 1997)—indicated that the retrieval memories were more 'semantically' similar to their triggers than prospective and introspective thoughts. Finally, the analysis also revealed how the content of one thought lead to another via 'thought trains'. For example, the thought 'beach nearby me at home that I always go to' led to 'my job as a beach tagger during high school' which led to 'a guy that I used to like'. These thought trains capture a key characteristic of mind wandering as argued by Christoff et al. (2016): 'wandering' means to 'move hither and thither without fixed course or certain aim' (p. 719).

4.3 | Decoupling and the cascade effect of mind wandering

A third aspect of the theoretical account pertains to how mind wandering affects comprehension outcomes. According to the *perceptual decoupling hypothesis* (Schooler et al., 2011), because mind wandering is internally driven, there is a decoupling of attention from the external environment and a disruption in stimulus processing (Smallwood, Beach, et al., 2008). This causes encoding failures (Seibert & Ellis, 1991), resulting in a weakened mental model and ultimately lower comprehension (Smallwood, McSpadden, & Schooler, 2008). This, in turn, increases the likelihood of future mind wandering episodes due to control failures stemming from an impaired mental model, resulting in a continuation of this vicious cycle. Similarly, Mills et al. (2017) proposed the idea of *cognitive coupling*—that resource allocation should be *coupled* to text demands, for example, that reading times should be longer when the difficulty of the text increases and vice versa. The distinction between perceptual and cognitive coupling/decoupling has to do with the level of analysis, such as a focus on low-order (e.g., word identification) and higher order processes (e.g., integration and inferencing).

Decoupling from the text—both perceptually and cognitively—should have negative consequences for reading comprehension. The *cascade model of inattention* (Smallwood, 2011) describes these downstream negative effects of mind wandering as occurring through superficial processing and missed (non-encoded) information that compound over time. It begins with attenuated processing at the lexical level which leads to missed surface level facts and ultimately an impoverished situation model (Kintsch, 1988). Thus, despite having some benefits (Mooneyham & Schooler, 2013) in certain contexts, mind wandering should be negatively correlated with reading comprehension outcomes, with decoupling being one potential mechanism (this is largely borne out in the data presented above).

4.4 | Moderating variables

We adopt theoretical perspectives (Goldman et al., 2016; Snow, 2002) which posit that reading involves an interaction among what the reader brings to the text (e.g., individual differences in motivation, reading ability, prior knowledge), the properties of the text itself (i.e., text characteristics such as text difficulty or genre), and the affordances of the reading context (e.g., contextual influences such as reading goal and reading environment [e.g., on the subway or in a library]). A good comprehender reading an editorial of great interest in a library will have a different experience than a struggling reader who reads the same text on the subway among the hustle and bustle of city life. Similarly, according to resource theories, reader differences should interact with task demands (e.g., a low comprehender is more likely to mind wander when reading a very difficult text) to predict mind wandering and task performance. Thus, the reader, text and context interact to set the stage for the core components of the model to unfold.

4.5 | Summary and claims

To summarize, we proposed an integrative model of mind wandering during reading that heavily builds upon existing theory and data, while making the following three claims. First, whereas most studies conceptualize mind wandering as *task*-unrelated and/or stimulus-independent thought, we suggest that it is beneficial to adopt a *goal*-directed perspective to understand mind wandering during reading. Second, though cut from the same cloth, mind wandering during reading is unique compared to other contexts where it is routinely investigated such as simplistic lab-based cognitive tasks and during mundane real-world activities (e.g., a commute). Third, the model emphasizes the importance of mediating (i.e., decoupling) and moderating variables in explaining the causes and consequences of mind wandering during reading and on reading outcomes.

5 | COMPUTATIONAL MODELLING

Computer scientists have been working alongside psychological scientists to develop computational models of mind wandering. The basic idea is that because mind wandering affects cognitive processing via decoupling (see Figure 2) it should be reflected in measurable behaviours such as reading times, eye gaze and facial expressions (e.g., Bosch & D'Mello, in press; Mills et al., 2017; Reichle et al., 2010). Thus, it should be possible to *automatically* make an inference of mind wandering (a latent construct) from observable behavioural signals via a *computational model*. This is done via a specific type of modelling approach as elaborated below.

5.1 | Machine-learned computational models (MLCM)

Models of eye movements during reading, such as E-Z Reader (Reichle et al., 2003) and SWIFT (Engbert et al., 2005), have been instrumental in advancing our understanding of the reading process. Unfortunately, research is too sparse for the precise mathematical formalisms and parameters needed to instantiate computational models of mind wandering during reading. Machine-learnt computational models (MLCM) (D'Mello et al., 2020) provide a promising alternative because the model is learnt from data rather than being pre-specified.

The core idea of the MLCM approach is to *learn* a computational model (a computer program) to identify, detect or infer unobservable mental states (mind wandering in this case) from observable signals (e.g., eye gaze) while people engage in a particular task (reading in our case) in a given context (e.g., a research lab). This is accomplished via a training phase where the model learns its parameters (and sometimes even its structure and representations) from *training data*. The critical test is whether the model can accurately estimate the focal mental state when presented with data from a *new* set of individuals (*holdout* set) in various contexts (generalizability). An accurate and generalizable model can be *analysed* for insights into the underlying phenomenon and/or *deployed* for automated measurement or real-time intervention.

Table 2 illustrates the steps involved in developing a computational model, both abstractly (left panel in Table 2) and with respect to modelling specific tasks: (1) mind wandering from eye movements (centre panel in Table 2) inspired by Faber et al. (2018a) and (2) emotions from facial expressions (right panel in Table 2) inspired by Bosch et al. (2016). The idea is to draw connections between the abstract steps and their concrete implementations in two studies (refer to the primary studies for details). In addition, Figure 3 provides a graphical representation of the steps involved in developing an eye-gaze-based MLCM of mind wandering during reading.

The MLCM process begins by recording *signals* (e.g., eye gaze) as people complete a task in a given context (e.g., reading in the lab). The data is *annotated* for the presence, absence, or degree of the construct to be measured, for example, by interspersing pseudo-random thought probes to measure mind wandering. The signals and annotations are temporally aligned by segmenting the signal data in short windows (e.g., 10 s) prior to the annotations. The annotations and features should be collected at multiple points from a given individual, from multiple individuals and across multiple contexts, so generalizable patterns can be learnt.

Next, the signals undergo several pre-processing steps (e.g., extracting gaze fixations from the raw eye gaze data), upon which higher order abstractions called *features* (e.g., number of gaze fixations, the average fixation duration) are computed within each segmented window. Then, *supervised learning* methods are used to learn complex, often nonlinear and interactive, associations between the features and the annotations, resulting in a computational model that can provide estimates of the construct in a *deployment phase*. Model performance is assessed by comparing the model estimates to the human annotations on holdout data. To summarize:

Supervised learning (features + **human annotations**) → *computational model*
Deployment (features + *computational model*) → **computer-annotations**

5.2 | Example of MLCMs of mind wandering

Most of the research on MLCMs of mind wandering have focused on eye movements. To illustrate, Faber et al. (2018a) collected training data from 132 participants from two sites (contexts) who read 57 pages (screens) of text displayed on a computer screen. Participants self-reported whenever they caught themselves mind wandering; see Bixler and D'Mello (2016) and Hutt et al. (2019) for examples using probe-caught mind wandering. A remote Tobii TX300 or T60 eye tracker (one per site) recorded eye gaze during reading; gaze fixations were extracted from these data. The stream of fixations was segmented into time windows (ranging from 4 to 12 s) prior to the self-reports; these were the positive instance of mind wandering. The researchers sampled eye gaze using similar-length windows from pages without a mind wandering report; these were the negative instances (i.e., not mind wandering). Four sets of gaze features were computed per window: eye movement descriptive features (e.g., mean, max), pupil diameter features, blink features and miscellaneous gaze features (see primary source for

TABLE 2 Steps involved in building a machine-learned computational model (MLCM) along with two example studies

	Step	Example Study 1: Gaze-based MLCM of mind wandering as participants read text in the lab	Example Study 2: Video-based model of affective states (emotions such as confusion, frustration, neural) as students engage with a learning game in classrooms
1.	Sensor/signal	Spatial-temporal eye gaze time series (signal) record from eye tracker (sensor)	Video of faces (signal) recorded from a web-cam (sensor) affixed on a computer monitor
2.	Labels/annotations	Self-reports of mind wandering	Trained observer judgements of emotions from visible behaviour
3.	Data	Signals and annotations collected as participants read text in the lab	Signals and annotations collected as students play a learning game
4.	Alignment	Eye gaze time series (#1) extracted in 8-s windows preceding a mind wandering report (#2)	Sequence of video frames (i.e. images, #1) extracted 30-s before an observer judgement (#2)
5.	Pre-processing	Fixations and saccades computed from the raw eye gaze data (#1) across the window (#4)	Facial expressions (smiles, frowns, etc.) extracted from the video frames (#1) in the window (#4)
6.	Feature computation	Global gaze features (e.g., number of fixations, fixation duration) computed from pre-processed data (#5)	Activation of facial expressions (e.g., number of smiles, head nods) computed from pre-processed data (#5)
7.	Supervised classification	Classifier trained to discriminate among positive and negative cases of mind wandering (#2) from global gaze features (#6)	Classifier trained to discriminate among confusion, frustration, and neutral (#2) from the facial expression features (#6)
8.	Validation	Accuracy based on alignment between annotated (#2) and classified mind wandering (#7)	Accuracy based on alignment between emotion estimates from the classifier (#7) and observer judgements (#2)
9.	Deployment	Validated computational models (#7) integrated into the reading interface to generate comprehension questions when mind wandering is detected	Validated computational models (#7) integrated into the learning game to provide hints and motivational scaffolds when confusion/frustration are detected (pending implementation)

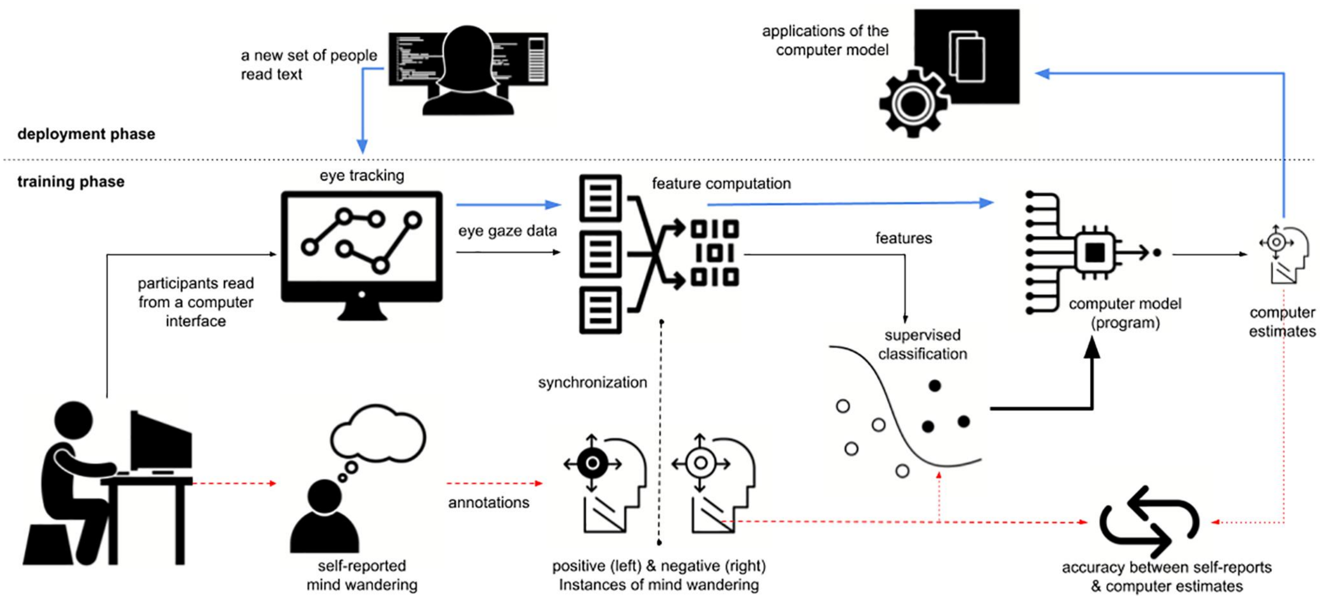

FIGURE 3 Schematic of steps involved in training a gaze-based machine-learned computational model of mind wandering (bottom of dotted line) and subsequent deployment of the trained model (top of dotted line); best viewed in colour. In a training phase, a set of participants' self-report mind wandering while an eye tracker simultaneously records their eye gaze, from which eye gaze features are computed. The gaze features and mind wandering reports are temporally aligned (synchronized) to create positive (mind wandering) or negative (normal reading) instances (cases). The instances are inputted to a supervised classification algorithm, which learns a computer model (program). Agreement between the model's estimates and the self-reports are used to measure accuracy. In a subsequent deployment phase, eye gaze data is collected from a new set of individuals who read text in a similar context but *do not* provide self-reports of mind wandering. Instead, eye gaze features are computed and submitted to the learned computer model, which generates computer-estimates of mind wandering, which can be subsequently used in various applications

details). The data were used to train supervised classification models to discriminate between positive and negative instances of mind wandering in a manner that would generalize to new participants (i.e., achieved by training models on a subset of participants and evaluating their predictions on held-out participants). Results indicated that the model predictions were significantly correlated ($r = 0.400$) with self-caught mind wandering and even predicted text comprehension more strongly ($r = -0.374$) than the self-reports ($r = -0.208$).

Other than eye gaze, some research has used physiological signals, such as electrodermal activity and skin temperature, to develop MLCMs of mind wandering during reading, either on a unimodal basis (Blanchard et al., 2014; Pham & Wang, 2015) or in conjunction with eye gaze (Bixler et al., 2015). Recent research has used facial expressions and body movements extracted from video, a difficult proposition because mind wandering is an internal state without well-understood visual correlates. To this point, Bosch and D'Mello (in review) report relatively low accuracies (57%) when nine untrained humans were asked to judge whether readers were mind wandering based on 10-s video clips (33% of clips reflected mind wandering). Remarkably, a computer vision algorithm (Bosch & D'Mello, in press) yielded similar accuracies (58%) to the humans on the same videos.

In summary, basic psychological research on the antecedents, behavioural correlates and consequences of mind wandering have inspired computer science researchers to develop computational models of mind wandering. The MLCM approach enables rapid development and testing of computational models of phenomena in the absence of well-developed theories, and ideally, modelling and theoretical development go hand in hand. And being fully instantiated computer programmes, MLCMs can be used for assessment and intervention as we elaborate next.

6 | INTERVENTION RESEARCH

The prevalence of mind wandering during reading and its negative association with comprehension suggests that there might be benefits to mitigate it. There are two main approaches. *Reactive interventions* respond to mind wandering as it occurs, which requires real-time assessments of mind wandering, whereas *proactive interventions* attempt to reduce mind wandering prior to or during the task at hand (e.g., reading) but are not based on any assessment.

6.1 | Reactive interventions

The idea of a reactive engagement is to reengage readers when in the midst of a mind wandering episode as well as correct gaps in their mental models before they continue reading, potentially assuaging downstream negative effects. In line with this, D'Mello, Mills, et al. (2017) developed an intervention to remediate gaps in textbase comprehension potentially due to mind wandering so as to halt the negative cascade effect into situation-level comprehension (Smallwood, 2011) and impaired learning (assessed after reading) (Figure 4). The intervention also aimed to reengage attention by disrupting ongoing mind wandering episodes. Accordingly, readers received a factual (i.e., textbase) multiple-choice question about the content of the page (screen of text) if an eye-gaze-based MLCM (Faber et al., 2018a) predicted that they were mind wandering while reading that page. When readers responded incorrectly, the computerized reading interface provided corrective feedback and prompted them to re-read the text. When

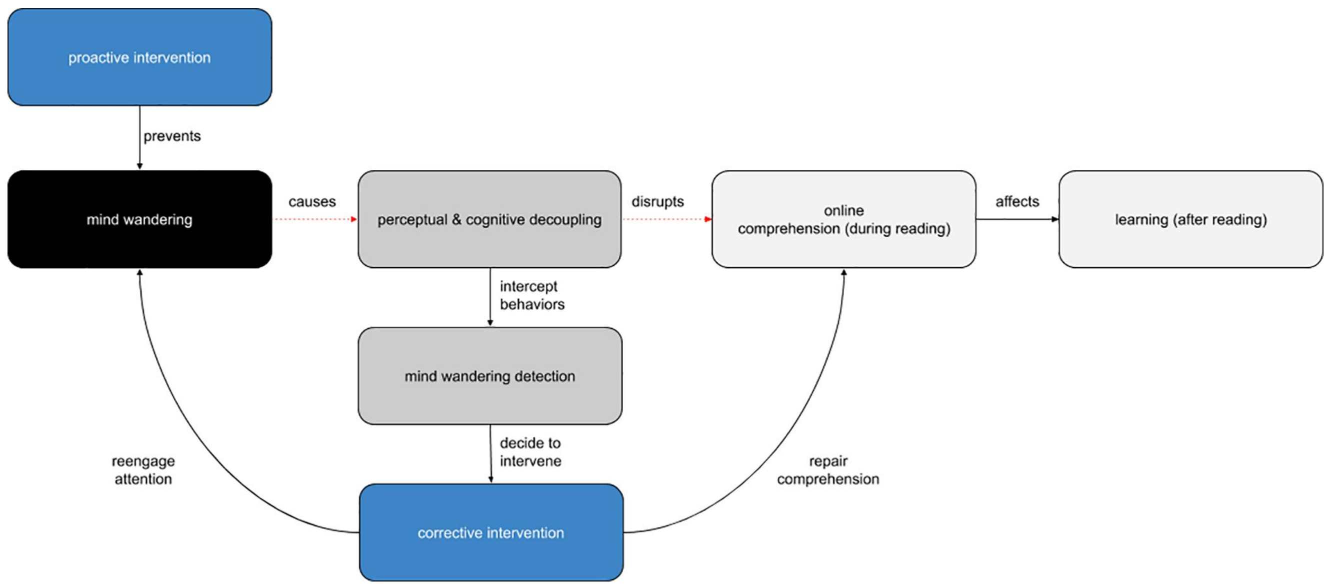

FIGURE 4 Sketch of processes and components involved in mind wandering detection and a corrective intervention to re-engage attention and repair comprehension to enhance learning

they indicated they were ready to move on, it provided them with a second question (either the same question or a different question on the same page). They were allowed to proceed to the next page irrespective of how they responded to this second question. Considerable care was taken to ensure that the interventions were not too disruptive and to prevent readers from feeling like they were being monitored.

To evaluate the intervention, each reader in the intervention condition was paired with a yoked-control participant who received the exact same interventions but independent of their mind wandering. After reading, all participants completed a different textbase comprehension assessment with items targeting specific pages. There were no significant differences between the conditions on overall comprehension. However, the intervention condition significantly ($d = 0.548$) outperformed the yoked-control condition for pages with low likelihoods of mind-wandering for the intervention group and high likelihoods of mind wandering for the control group; there were no differences for the reverse case. This suggests that the intervention had the intended effect of reducing comprehension deficits attributable to mind wandering because it led to equitable performance when mind wandering was high and improved performance when it was low. Despite some benefit, the intervention was limited to textbase-level comprehension, which may have encouraged keyword spotting and a generally shallow-level processing style.

A second study (Mills et al., in press) improved this intervention by targeting deeper levels of comprehension using self-explanations, a well-studied deeper comprehension strategy (Chi et al., 1989; McNamara, 2004). When mind wandering was detected using the same gaze-based MLCM, readers were asked to construct (from memory) a written self-explanation targeting text concepts that spanned multiple pages of text rather than textbase questions on individual pages as in the earlier intervention. The self-explanations were automatically scored in real-time, and readers were prompted to re-read the text to improve their responses if scores were low. This revised intervention was also compared to a yoked-control condition who received the exact same interventions regardless of their mind wandering. The two conditions performed similarly on a comprehension assessment immediately after reading. However, after a week-long delay, the experimental condition outperformed the control condition on both textbase- and inference-level comprehension assessments (d's $= 0.35$ and 0.31 sigma, respectively).

These studies demonstrate the feasibility and benefits of computer interfaces that detect and respond to mind wandering in real-time. There have also been efforts to develop intervention strategies for real-world applications where multiple consumer-grade eye trackers were used to detect and respond to mind wandering in computer-enabled high-school classrooms (Hutt et al., in press).

6.2 | Proactive interventions

Proactive interventions aim to reduce mind wandering before reading (either dispositionally or situationally) or in the midst of reading, but do not utilize real-time mind wandering detection as in the case of the reactive interventions. The majority of dispositional proactive interventions focus on mindfulness training (Mrazek et al., 2017), which encourages non-judgemental attentional control through attention regulation. That is, people are trained to immediately re-orient attention back to the present moment when anything other than the present moment comes into focus (Jha et al., 2007; Mrazek et al., 2013). Long-term mindfulness training has been shown to reduce mind wandering and improve task performance (Mrazek et al., 2013), even in the context of reading (Zanesco et al., 2016). However, brief situational based mindfulness training (less than 30 min) have been less effective (Clinton et al., 2018; Krasich, Hutt, et al., 2018). For example, Clinton et al. (2018) found that readers performed better on comprehension assessments after a short breathing-based mindfulness intervention, but mind wandering was unaffected, and thus an unlikely mechanism for any intervention benefits.

Previous work reviewed above suggests that manipulating aspects of the task context or text can reduce mind wandering, and these basic findings can be turned into interventions. With respect to the task context, interpolated testing, which involves interspersing test items throughout a task, has been shown to dramatically reduce (from 40% to 20%) mind wandering while viewing lecture videos (Szpunar et al., 2013), ostensibly because the interventions improved motivation, which negatively predicts mind wandering (Robison et al., 2020). Reading comprehension interventions which employ interpolated testing, for example, via self-explanations (Chi et al., 1994), should expect similar reductions in mind wandering, though this has yet to be empirically tested. Other context features to consider are text presentation format (length, typeface, etc.) similar to the study finding that disfluent text lowered mind wandering rates (Faber et al., 2017) and the section-length effect elaborated earlier (Forrin et al., 2019). Manipulations of text features may include identifying optimal task demands (i.e., difficulty) for individual readers by finding their 'regions of proximal learning' (Xu & Metcalfe, 2016) or areas of resource sensitivity (Randall et al., 2019).

Reader differences may also be leveraged to reduce mind wandering by personalizing the text and reading environment. To this point, a simulation study by Kopp et al. (2014) suggested that measurement of individual differences (e.g., working memory, interest, reading fluency) prior to reading could be used to assign reading conditions (e.g., easy vs. difficult texts and high vs. low stakes assessments after reading) to reduce mind wandering for individual readers. Further, situational reader variables known to reduce mind wandering include topic interest (Fulmer et al., 2015; Soemer & Schiefele, 2019) and mood (Smallwood et al., 2009), which can be induced prior to reading.

To sum up, mind wandering is malleable and can be addressed in several ways. One approach is to use real-time measures to inform dynamic interventions that aim to reengage readers and correct comprehension deficiencies. The second approach is to proactively address mind wandering by leveraging basic research without relying on sophisticated computational modelling. Of course, proactive interventions are not expected to eliminate mind wandering entirely, leaving open the possibility of reactively responding when it inevitably arises. A combination of the two might be ideal.

7 | SUMMARY, PROMISING FUTURE DIRECTIONS AND CONCLUDING REMARKS

If you followed our initial instruction, you might have noted a few instances where your mind wandered while reading this article. This is to be expected; mind wandering is pervasive during reading and is negatively associated with comprehension outcomes. The purpose of this article was to organize and review pertinent research on mind wandering during reading. Our approach was to (1) provide a general overview of mind wandering including definition, causes, measurement and neural correlates; (2) review cognitive and behavioural research on the influences, consequences and moderators of mind wandering during reading; (3) propose an integrative working theoretical account of mind wandering specific to reading; (4) introduce MLCMs of mind wandering and (5) discuss intervening to reduce mind wandering either reactively or proactively. We end with our thoughts on some unresolved questions along with promising items for future research.

7.1 | What is mind wandering?

Mind wandering, like many psychological constructs including emotion (Izard, 2010) and consciousness (Seth et al., 2005), is difficult to define (Seli, Kane, Smallwood, et al., 2008). Our advice to avoid definitional paralysis is to select an operational definition and avoid making generalizations that are not specific to the selected definition. We suggest that in the context of reading, at a minimum, a thought needs to be incongruent to the comprehension goal to be considered mind wandering. We also consider mind wandering to be unintentional and dynamic—the 'wandering' component, but acknowledge this is still debated (e.g., Christoff et al., 2018; Mills et al., 2018; Seli, Kane, Metzinger, et al., 2018). Importantly, our working definitions of mind wandering have changed across the years as we have learnt more about wandering minds.

7.2 | How long is a mind wandering episode?

A very exciting and largely unanswered question pertains to the length of a mind wandering episode. Preliminary studies from eye tracking (Krasich, McManus, et al., 2018), narrative comprehension (Faber et al., 2018b), and re-reading after a mind wandering episode (Varao-Sousa et al., 2017) suggest a 10–15 s window, but this is quite speculative. Creative research designs and new methodological techniques might be needed to address this question. We think automated measures (see below), which can yield unobtrusive, continual, high-frequency estimates of mind wandering (e.g., every 500–1000 ms) in real time (see Hutt et al. (2019) have considerable promise to yield some significant breakthroughs.

7.3 | What is the afterglow of mind wandering?

Most research has focused on the factors or events leading up to a mind wandering episode. Whereas there have been some works on the delayed effects of mind wandering, there is a paucity of research on the moments following a mind wandering episode. Based on self-report data, Varao-Sousa et al. (2017) suggest that readers have a 50% likelihood of re-reading 1–2 previously read lines of text after a mind wandering episode, presumably to repair their mental models. Other than this early work suggesting a form of corrective responding, we know little about the short-term (100 ms–5 s) consequences of a wandering mind caught in flight. On a similar vein, more research is needed to better integrate mind wandering within extant models of reading comprehension (McNamara & Magliano, 2009), which espouses numerous processes such as backward/forward inferencing, comprehension monitoring, comprehension repair and so on.

7.4 | Are effects reading-specific versus more generalized?

Reading is a unique task, which raises the question about how research findings from non-reading studies apply to reading. We argued that mind wandering in semantically impoverished vigilance or working memory tasks might not generalize to semantically rich tasks like reading and other forms of narrative processing. There might be a middle ground. In a recent study with seven different tasks, Faber et al. (2020) found that gaze behaviours during mind wandering reliably patterned with respect to task demands in terms of spatial allocation, visual processing and discourse processing, suggesting a *task-resemblance hypothesis*. Uncovering patterns specific to reading, reading-related (e.g., other narrative processing) versus unrelated tasks would be a fruitful goal.

7.5 | Are there genre effects?

Much of the research reviewed in this article and our working theoretical account assumes that the goal of reading is comprehending and learning from text. Whereas this may be the case for informational, expository, and perhaps even some narrative texts, a reader of literary texts may adopt an entirely different goal, for example, reflecting on the underlying rhetorical structure or admiring the use of metaphor, irrespective of the actual narrative arc of the text. Fabry and Kukkonen (2019) suggested that investigating mind wandering during reading of literary texts might entail an entirely different research approach and proposed an alternate theoretical perspective of enculturated predictive processing than the standard models of comprehension (McNamara & Magliano, 2009). Whereas a traditional conceptualization of mind wandering as 'off-task thought' in most reading studies might be too vague to discriminate, for example, among processing the textual content versus the literary structure of a text, it does distinguish thoughts about laundry, an unrelated memory, or the room temperature, suggesting that perhaps the concern is a bit overstated. Nevertheless, whereas both literary and non-literary texts have been used in mind wandering research, the two have been rarely compared,[7] and investigating genre effects is a very pertinent question for future work.

7.6 | Complex interactions and nonlinearity

We adopt the widely held position (Snow, 2002) that reading-related states/processes like mind wandering emerge from complex interactions among the text, task context and reader. The empirical studies we reviewed supported this view, albeit with respect to two-way interactions and linear effects. Studies on more complex three-way interactions were more limited, particularly in the context of reading. Also limited, were studies investigating non-linear effects, suggesting an important area for future work. For example, is there a U-shaped curve among text difficulty and mind wandering, where mind wandering is lowest for moderately difficult texts compared to very easy and very difficult texts? And is the nonlinear effect moderated by interest and working memory capacity?

7.7 | The promise of advanced, automated and analytic measurement

Measurement is a precursor to change and the use of self-reports to measure mind wandering constrains research advances. Fortunately, as we argued here and elsewhere (D'Mello et al., 2020), MLCMs of mind wandering offer a unique opportunity for advanced, automated and analytic measurement of mind wandering and related constructs including engagement and emotion (D'Mello, Dieterle, & Duckworth, 2017). Further, many of the models have utilized eye tracking as their primary modality (Faber et al., 2018a; Hutt et al., 2019), which makes the approach particularly well suited to reading research, which has long since embraced this technology (Rayner, 2009). These measures can also be used outside of the lab via consumer-grade eye tracking (Hutt et al., 2019) and even with web-cams (Bosch & D'Mello, 2021), thereby offering unobtrusive measurement at scale. We leave it to the imagination of the reading researcher to ponder how best to incorporate these technologies in their research.

7.8 | From foundational research to translational applications

Finally, we encourage researchers to consider the translational potential of their discoveries and technologies. The foundational research on mind wandering can benefit millions of people around the world who struggle with maintaining attentional focus for a variety of reasons. These include neurodiverse individuals, those who are learning to read, and each and every one of us who has struggled to focus due to worries, fatigue, environmental distractions and numerous other factors. As elaborated earlier, many of the basic research findings on the antecedents of mind wandering can be translated into proactive interventions which can reduce mind wandering. Similarly, the MLCM models can be used to measure mind wandering to improve awareness and metacognition, to evaluate the 'interestingness' of texts, and to trigger real-time interventions. Of course, translating laboratory findings to real-world applications is an endeavour fraught with complexity and risk, but it is an essential step for research to remain relevant and to contribute to broad societal good. Insights from the field of translational science can provide a head start.

In conclusion, the important take home message for reading researchers, educators and authors is this: even though your readers appear to be reading intently, there are times when they have no idea what they are reading because their minds may have wandered miles away. Monitoring mind wandering during reading can provide an important clue into reader engagement and reading outcomes, which provides opportunities for intervention. Further, state-of-the-art methods from the computing sciences make it possible to automatically identify when a reader is mind wandering in real time in a non-disruptive manner, thereby providing an important diagnostic of the reading process while simultaneously opening the door to interventions to improve reading outcomes.

ACKNOWLEDGEMENTS

This research was supported by the National Science Foundation (NSF) (DRL 1235958, IIS 1523091l, and DRL 1920510). Any opinions, findings and conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the NSF.

CONFLICT OF INTEREST

The authors do not have any conflicts.

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ENDNOTES

[1] This is based on searching the term 'mind wandering' (performed on October 9, 2020) in two prominent reading and text comprehension journals. The search yielded only three hits in *Scientific Studies of Reading*, of which only one was a bona fide study on mindless reading (Nguyen et al., 2014). A similar search yielded 17 articles in *Discourse Processes*; of which only a handful focused on mind wandering per se (e.g., Dixon et al., 2015).

[2] Taking a somewhat different approach, Soemer and Schiefele (2019) and Soemer et al. (2019) found that topic interest fully *mediated* the effect of text difficulty on mind wandering in that the more difficult texts were perceived as being less interesting, and lower interest was associated with higher mind wandering. However, unlike Fulmer et al. (2015), they did not manipulate interest, but measured it *after* reading, whereas mind wandering was measured *during* reading, suggesting that causal direction of the effects is unclear (i.e., those who mind wandered more while reading might have considered the text to be less interesting).

[3] The specific studies examined include (Bortolussi & Dixon, 2015; Dixon & Bortolussi, 2013; Dixon & Li, 2013; Foulsham et al., 2013; Franklin et al., 2011; Jackson & Balota, 2012; Krawietz et al., 2012; McVay & Kane, 2012; Reichle et al., 2010; Smallwood, McSpadden, & Schooler, 2008; Unsworth & McMillan, 2013). Whereas Randall et al. (2014) categorizes Risko et al. (2012) as a reading comprehension study, it is in fact a study on online lectures, so it is excluded here.

[4] The specific studies include (Faber et al., 2020; Faber et al., 2017; Feng et al., 2013; Fulmer et al., 2015; Kopp et al., 2015; Kopp & D'Mello, 2016; Mills et al., 2015; Mills et al., 2013; Mills et al., 2017; Phillips et al., 2016) plus one unpublished study.

[5] Beyond immediate comprehension of the text, Sanchez and Naylor (2018) found that mind wandering while reading a text on plate tectonics was associated with more misunderstandings and fewer identified causes of volcanic eruptions.

[6] There appear to be age-related differences in the content of mind wandering during reading. Krawietz et al. (2012) found that younger adults (17–22 years) were more likely to report self-focused thoughts compared to older adults (58–87 years; 22% vs. 10% and 20% to 5% in Experiments 1 and 2, respectively), who were more likely to report text-related thoughts (10%–34%; 10%–51% in Experiments 1 and 2, respectively).

[7] The one study that directly compared reading across genres did not measure mind wandering but analysed cognitive coupling instead (Goedecke et al., 2015).

[8] Some studies ask participants to categorize their zone-outs on dimensions such as intentionality (of mind wandering) and thought-content such as sensory and emotional states, the self, current concerns, prospective memory, stimuli, environmental distractions and fantasies (Baumeister et al., 2016; Krawietz et al., 2012; Phillips et al., 2016; Schooler et al., 2004; Smallwood et al., 2016; Song & Wang, 2012).

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How to cite this article: D'Mello SK, Mills CS. Mind wandering during reading: An interdisciplinary and integrative review of psychological, computing, and intervention research and theory. *Lang Linguist Compass*. 2021;e12412. https://doi.org/10.1111/lnc3.12412