AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Experimental Psychology:
Human Perception and Performance

ISSN: 0096-1523

2020, Vol. 46, No. 10, 1201–1221
http://dx.doi.org/10.1037/xhp0000743

The Eye–Mind Wandering Link: Identifying Gaze Indices of Mind Wandering Across Tasks

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During mind wandering, visual processing of external information is attenuated. Accordingly, mind wandering is associated with changes in gaze behaviors, albeit findings are inconsistent in the literature. This heterogeneity obfuscates a complete view of the moment-to-moment processing priorities of the visual system during mind wandering. We hypothesize that this observed heterogeneity is an effect of idiosyncrasy across tasks with varying spatial allocation demands, visual processing demands, and discourse processing demands and reflects a strategic, compensatory shift in how the visual system operates during mind wandering. We recorded eye movements and mind wandering (via thought-probes) as 132 college-aged adults completed a battery of 7 short (6 min) tasks with different visual demands. We found that for tasks requiring extensive sampling of the visual field, there were fewer fixations, and, depending on the specific task, fixations were longer and/or more dispersed. This suggests that visual sampling is sparser and potentially slower and more dispersed to compensate for the decreased sampling rate during mind wandering. For tasks that demand centrally focused gaze, mind wandering was accompanied by more exploratory eye movements, such as shorter and more dispersed fixations as well as larger saccades. Gaze behaviors were not reliably associated with mind wandering during a film comprehension task. These findings provide insight into how the visual system prioritizes external information when attention is focused inward and indicates the importance of task demands when assessing the relationship between eye movements, visual processing, and mind wandering.

Public Significance Statement

Efforts to study and model gaze control do not currently consider the impact of mind wandering, which obfuscates a clear understanding of how the visual system samples information across various attentional states. The current works indicates that mind-wandering-based gaze behaviors reflect shifts in gaze control that are idiosyncratic to the task-relevant visual and discourse processing demands as well as spatial allocation demands, rather than a completely generalizable principle for how the visual system operates when not avidly engaged with the external world. This work thus provides a framework for empirical investigations and models of gaze control to consider mind wandering within specific tasks parameters.

Keywords: mind wandering, eye movements, cognitive processing, visual processing

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We thank past and current members of the Emotive Computing Lab for their assistance in data collection. This work was supported by the National Science Foundation (NSF; DRL 1235958, IIS 1523091, and DRL 1920510). Any opinions, findings and conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the NSF.

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An in-depth analysis of the visual world lures humans into moving their eyes. This originates from a visual system that is both physically (e.g., visual acuity) and cognitively (e.g., attention and memory) constrained such that central vision is required for fine-grained analysis of external input. With each *fixation*—a period of time when the eyes remain relatively still—valuable information is extracted, evaluated, and used to determine where the eyes should look next. The eyes will shift from location to location—through ballistic movements known as *saccades*—to best serve the individual's goals. Accordingly, gaze allocation in time and space is thought to provide a real-time index of the information-processing priorities of the visual system, and this is commonly referred to as the "eye–mind link" (Just & Carpenter, 1976; Rayner, 1998; Reichle, Pollatsek, & Rayner, 2012).

What if, however, the mind is not focused on what the eyes see? People are frequently disengaged from the here-and-now via attentional shifts away from the task to task-unrelated thoughts, a state of attention known as mind wandering (Smallwood & Schooler, 2006). Indeed, laboratory and field-based research has repeatedly shown that people report that 20% to 50% of their thoughts are spent on mind wandering (Killingsworth & Gilbert, 2010; Smallwood & Schooler, 2015; although see Seli et al., 2018). Mind wandering is considered to be a perceptually decoupled state of attention wherein external information processing is deprioritized in favor of internal thoughts (Schooler et al., 2011; Smallwood, Beach, Schooler, & Handy, 2008). Following the eye–mind link, the shifts in attentional priorities that occur during mind wandering should be associated with systematic alterations in gaze allocation. Understanding these changes will therefore provide insights into how the visual system operates to accomplish task goals when doing so is not an attentional priority. As such, a growing body of literature has sought to differentiate gaze behaviors associated with mind wandering from those that occur during attentive viewing.

A comprehensive understanding of gaze behaviors during mind wandering has proven difficult, though, because, as we review in the following text, a number of inconsistencies have emerged in the empirical findings. This begs the question whether a single set of mind-wandering-based gaze behaviors exists. If so, one could uncover a general principle for how the visual system adapts during mind wandering. If not, idiosyncrasy among tasks may reveal how the visual system uniquely shifts its processing priorities to achieve specific task goals during mind wandering.

We explore this central question by first describing contemporary views on gaze control during attentive viewing followed by a review of the growing body of literature on the "eye–mind wandering link" to highlight existing consistencies/disparities across studies. We then investigate mind-wandering-based gaze behaviors across seven cognitive tasks that vary in visual processing demands, discourse processing demands, and spatial allocation demands. Our goals were to account for the potentially heterogeneous nature of gaze behaviors associated with mind wandering, provide insights into the visual processing priorities of the visual system when attention is decoupled from the external world, and offer a theoretical account for how visual processing is maintained—albeit impaired—during mind wandering.

Theoretical Background and Previous Research

How the Visual System Extracts and Evaluates Information

There are a number of known factors that influence where and when the eyes look. For instance, when people look at pictures of scenes, they tend to look more frequently at regions that are visually salient (e.g., Harel, Koch, & Perona, 2007; Itti & Koch, 2000, 2001; Itti, Koch, & Niebur, 1998), objects that are semantically informative (e.g., Henderson & Hayes, 2017, 2018; Henderson & Hollingworth, 1999; Loftus & Mackworth, 1978; Mackworth & Morandi, 1967), and objects that are related to completing task goals (e.g., Land & Hayhoe, 2001; Land & Lee, 1994; Yarbus, 1967). The amount of time spent looking in these areas of a scene is then related to the ease with which information can be recognized and understood (e.g., Becker, Pashler, & Lubin, 2007; Bonitz & Gordon, 2008; Castelhano & Henderson, 2007; Henderson & Castelhano, 2005; Hollingworth, 2006; Underwood, Templeman, Lamming, & Foulsham, 2008). For example, fixations tend to lengthen when the discriminability of sensory information is diminished (Reddi, Asrress, & Carpenter, 2003) or expectations of the observer are reduced (Carpenter & Williams, 1995). Accordingly, longer fixation durations during scene viewing are thought to reflect a more in-depth evaluation of visual information (e.g., Henderson, 2011; Henderson & Choi, 2015; Nuthmann, Smith, Engbert, & Henderson, 2010) and the time needed to use that information to decide where to look next (Tatler, Brockmole, & Carpenter, 2017).

The connection between fixation durations and processing demands is also observed in contexts beyond object and scene processing. For instance, during normal reading (in English), fixation durations typically vary as a function of the length, frequency, and processing difficulty of the words in the text (e.g., Juhasz & Rayner, 2003, 2006; Rayner & Duffy, 1986; Reichle, Rayner, & Pollatsek, 2003). That is, fixations tend to linger on more "difficult" words, such as infrequent (Inhoff & Rayner, 1986; Raney & Rayner, 1995) and abstract words (Juhasz & Rayner, 2003), a pattern thought to reflect the extended time needed for greater lexical and orthographic processing for these difficult words (e.g., Rayner & Duffy, 1986; Sereno, Pacht, & Rayner, 1992). In contrast, fixations tend to be shorter when a reader is skimming the text (Rayner, Pollatsek, Ashby, & Clifton, 2012). The angular distance of saccades (saccade amplitude) will also typically become shorter in more difficult texts, which suggests an increase in the number of words that are fixated, processed, and understood to compensate for the higher processing demands (Rayner, 1998).

Interestingly, there are even gaze behaviors associated with tasks that have virtually no visual processing demands, but gaze may, nonetheless, still operate to serve task goals. For instance, some findings have shown that while listening to verbal descriptions of a previously viewed scene, participants have a tendency to look at areas on a blank screen where the described objects had previously been located (e.g., Altmann, 2004; Johansson, Holsanova, Dewhurst, & Holmqvist, 2012; Johansson, Holsanova, & Holmqvist, 2006; Staudte & Altmann, 2017) or ought to be located (Demarais & Cohen, 1998). It is hypothesized that these gaze behaviors can aid in memory retrieval (Ferreira, Apel, & Henderson, 2008; Johansson & Johansson, 2014; Richardson, Altmann, Spivey, & Hoover, 2009) and/or mental concentration (Gopher, 1973; Harrison & Irving, 1966; Teitelbaum, 1954). The collective point here is that even under conditions with virtually no external visual processing demands, systematic gaze behaviors can be observed and these behaviors can, in turn, offer insights into how the visual system operates to serve task goals.

Visual Processing During Mind Wandering

Investigating mind-wandering-based gaze behaviors is important for further understanding visual processing because of the perceptual decoupling thought to occur during mind wandering (Schooler et al., 2011; Smallwood et al., 2008). Specifically, evidence from electroencephalography (EEG) shows reduced early cortical processing of visual stimuli associated with mind wandering, as measured by an attenuated P1 event-related potential (ERP) component (Baird, Smallwood, Lutz, & Schooler, 2014; Kam et al., 2011; Smallwood et al., 2008)—the ERP component associated with early low-level visual processing (Hillyard, Hink, Schwent, & Picton, 1973). Mind wandering is also associated with reduced cortical processing of both task-related and task-unrelated stimuli, as measured by reduced mean amplitude measures of the P3 ERP component (Barron, Riby, Greer, & Smallwood, 2011). These findings suggest a global reduction in cortical processing of external information during mind wandering. Moreover, reading studies focusing on behavioral measures, such as reading times, have provided complementary evidence for the perceptual decoupling associated with mind wandering (e.g., Faber, Mills, Kopp, & D'Mello, 2017; Franklin, Smallwood, & Schooler, 2011; Mills, Graesser, Risko, & D'Mello, 2017).

From this, it follows that the reduction of visual processing during mind wandering should correspond with shifts in gaze that reflect how the visual system operates when external information is deprioritized during mind wandering. Accordingly, mind wandering has been linked to a number of temporal and spatial changes in gaze behaviors. As we review in the following text, however, findings have not revealed consistent gaze behaviors associated with mind wandering, obfuscating a clear understanding of the visual processing priorities of the visual system.

Gaze Behaviors Associated With Mind Wandering

The majority of research on gaze behaviors and mind wandering has been done in the context of reading. These studies have found deviations in gaze patterns from attentive reading, which, when considered collectively, suggest a decoupling between gaze and the text (Faber, Bixler, & D'Mello, 2018; Loboda, 2014; Reichle, Reineberg, & Schooler, 2010; Schad, Nuthmann, & Engbert, 2012). For example, in one study, self-reported mind wandering was linked to longer fixation durations, with observable differences up to 120 s prior to the self-report (Reichle et al., 2010). This finding is perhaps curious given that longer fixations during attentive reading, as we previously described, are typically thought to signal greater lexical and linguistic processing (e.g., Rayner & Duffy, 1986; Sereno et al., 1992). It is important to note, though, that unlike attentive reading, the variability in fixation durations associated with mind wandering was unrelated to word length or frequency, which suggests that these longer fixation durations were unrelated to content-specific linguistic processing (Reichle et al., 2010). Furthermore, mind wandering was also associated with fewer regressions to previously fixated words (Reichle et al., 2010), a finding that has been replicated in other studies (e.g., Foulsham, Farley, & Kingstone, 2013; Uzzaman & Joordens, 2011) and suggests reduced corrective responding during mind wandering. When considered together, these findings suggest that gaze-based signatures of mind wandering can indicate impaired text processing (Schad et al., 2012).

Despite the progress made in linking gaze and mind wandering in reading, there are examples of heterogeneity in the literature (Steindorf & Rummel, 2019). For instance, whereas some reading studies have also observed longer fixation durations associated with mind wandering (Faber et al., 2018; Foulsham et al., 2013; Frank, Nara, Zavagnin, Touron, & Kane, 2015; Reichle et al., 2010), others have failed to replicate this effect (Smilek, Carriere, & Cheyne, 2010; Uzzaman & Joordens, 2011). A recent study (Steindorf & Rummel, 2019) attempted to resolve these inconsistencies but found that mind wandering was associated with more frequent fixations, which contradicts past findings, and the disconnect between fixation durations and word frequency during mind wandering, as observed in Reichle et al. (2010), was found to be a weak effect. Therefore, a clear set of gaze behaviors associated with mind wandering in reading remains unidentified.

The challenge with establishing a single set of mind-wandering-based gaze behaviors is certainly not confined to reading tasks, however. For instance, attempts to use predictive modeling methods (such as those described by Yarkoni & Westfall, 2017) to develop computational models of mind wandering from gaze have not yet identified a common set of gaze parameters that can be used across tasks. To illustrate, in a study of narrative film comprehension, a decrease in saccades onto and off of the most visually salient region in the film (a bright, moving red balloon) was an important gaze-based predictor of mind wandering (Mills, Bixler, Wang, & D'Mello, 2016), which suggests that content-specific features of the visual display are important for understanding how gaze control is influenced by mind wandering. In contrast, in the context of watching a video lecture, content-dependent relationships (e.g., whether gaze is focused on a salient area of interest) did not improve the detection of mind wandering over and above the global gaze parameters, such as the number and duration of fixations and saccades as well as saccade amplitude (Hutt, Hardey, et al., 2017).

The Current Study

The studies we described in the preceding text indicate a challenge in establishing a single set of gaze behaviors that consistently reflect mind wandering. When considering the process by which the visual system extracts, evaluates, and uses information to determine gaze allocation, however, it is perhaps not surprising that establishing a consistent link between mind wandering and gaze is proving to be difficult. That is, it is possible that mind-wandering-based gaze behaviors should be characterized as idiosyncratic deviations from attentive viewing that reflect strategic shifts in how gaze is reallocated during mind wandering to serve specific task goals. Following this idea, there should not be a single set of gaze behaviors that consistently reflects mind wandering, but rather mind-wandering-based gaze behaviors should vary across tasks. This idea, however, does not account for studies that show consistencies in fixation patterns (fewer and longer fixations) across reading (e.g., Bixler, Blanchard, Garrison, & D'Mello, 2015; Foulsham et al., 2013; Frank et al., 2015; Reichle et al., 2010) and scene viewing (Krasich, McManus, Hutt, Faber, D'Mello, & Brockmole, 2018) tasks. Therefore, we considered an intermediate position: perhaps tasks that share similar task demands will elucidate similar mind-wandering-based gaze behaviors than dissimilar tasks. We termed this idea the *task-resemblance hypothesis.*

To test this hypothesis, we first considered several task demands that might influence mind-wandering-based gaze behaviors. Specifically, we considered the *spatial allocation demands*—defined here as the extent to which attention and gaze must be allocated extensively throughout the display or remain centrally focused within the display to complete task goals. We also considered the visual processing demands—the degree to which visual information must be extracted and evaluated by the neurocognitive process of the visual system—because tasks with high (as opposed to low) visual processing demands might be greatly affected by perceptual decoupling during mind wandering. Last, we considered the discourse processing demands—how levels of a mental representation of a connected discourse are dynamically built during comprehension (Graesser, Millis, & Zwaan, 1997)—which is known to break down during mind wandering (Smallwood, McSpadden, & Schooler, 2008).

According to our task-resemblance hypothesis, tasks with similar demands should evoke similar mind-wandering-based gaze behaviors. That said, an open question is which task demand might yield consistent or varying mind-wandering-based gaze behaviors. We therefore selected a battery of tasks that shared certain demands while varying others (detailed further in the following text). Rather than strictly controlling for each demand for our comparisons, we selected tasks that represent a multitude of everyday activities, thus providing ecological validity to our work. Last, we compared mind-wandering-based gaze behaviors across these tasks (listed in Table 1 and illustrated in Figure 1) to observe whether any consistent patterns would emerge across tasks.

Battery of Cognitive Tasks

Our tasks varied in spatial allocation demands, visual processing demands, and discourse processing demands and we next briefly describe and compare these demands within as well as across our tasks (see the Method section for detailed task procedures).

Reading. We started by including a reading task (reading; see Figure 1, Panel A) because mind-wandering-based gaze behaviors have been most frequently studied in the context of reading, and findings have been inconsistent across studies. The reading task we selected has been used in other studies (Kopp & D'Mello, 2016) and required high visual processing, high discourse processing, and extensive spatial allocation to accurately comprehend the text.

Scenes. We next included a scene viewing task (see Figure 1, Panel B) for several reasons. First, research on gaze control has frequently used scene viewing tasks as a proxy for how the visual system samples information in the real world. Second, only one study has previously investigated mind-wandering-based gaze behaviors in a scene viewing task, and this study found that, similar to reading, mind wandering was associated with fewer and longer fixations (Krasich et al., 2018). Therefore, our study allowed us to investigate whether similar patterns would emerge across reading and scene viewing tasks within the same group of participants. The specific scene viewing task we included required extensive sampling of the visual display (extensive spatial allocation demands), high visual processing demands, but low discourse processing demands. This allowed us to assess how mind-wandering-based behaviors differed in tasks with similar spatial allocation and visual processing demands but varying discourse processing demands.

Illustrated text. We also included a task where participants were asked to comprehend an illustrated text (illustrated text; see Figure 1, Panel C), which required reading a short passage and surveying an associated image in the same visual display. Therefore, this task provided an interesting comparison to the reading and scenes tasks as a blend of the two by which we could explore consistencies/disparities across these three tasks. The consistent commonality across these three tasks were the extensive spatial allocation and high visual processing demands, but discourse processing demands varied across these tasks.

Audiobook. We included a task where participants listened to an audiobook while looking at a fixation cross (audiobook; see Figure 1, Panel D). Although a fixation cross has limited ecological validity, it encouraged participants to keep their eyes open and directed on the screen so that gaze behaviors could be computed. The audiobook task offered an additional comparison to the reading task because it also required high discourse processing but demanded central (rather than extensive) spatial allocation and virtually no visual processing. This allowed us to gauge mind-wandering-based gaze behaviors across tasks with similar discourse processing but with varying spatial allocation and visual processing demands.

Sustained attention to response task (SART). To also compare with the audiobook task, we included a sustained attention to response task (see Figure 1, Panel E). This task requires participants to remain highly vigilant to centrally presented stimuli and to respond to all stimuli except for infrequent targets (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). The SART has also been used in other studies of mind wandering (e.g., Smallwood, Riby, Heim, & Davies, 2006). Like the audiobook task, the SART required central spatial allocation and low visual processing. Unlike the audiobook task, though, our version of the SART required no discourse processing. Therefore, by comparing with the audio-

Table 1
A List of Tasks Characterized by Spatial Allocation Demands, Visual Processing Demands, and Discourse Processing Demands

Spatial allocation	Visual processing	Discourse processing	Task
Extensive	High	High	Reading
		Low	Scenes
		High	Illustrated text
Central	Low	High	Audiobook
		Low	SART
	High	High	Lecture
		Low	Film

Note. SART = sustained attention to response task.

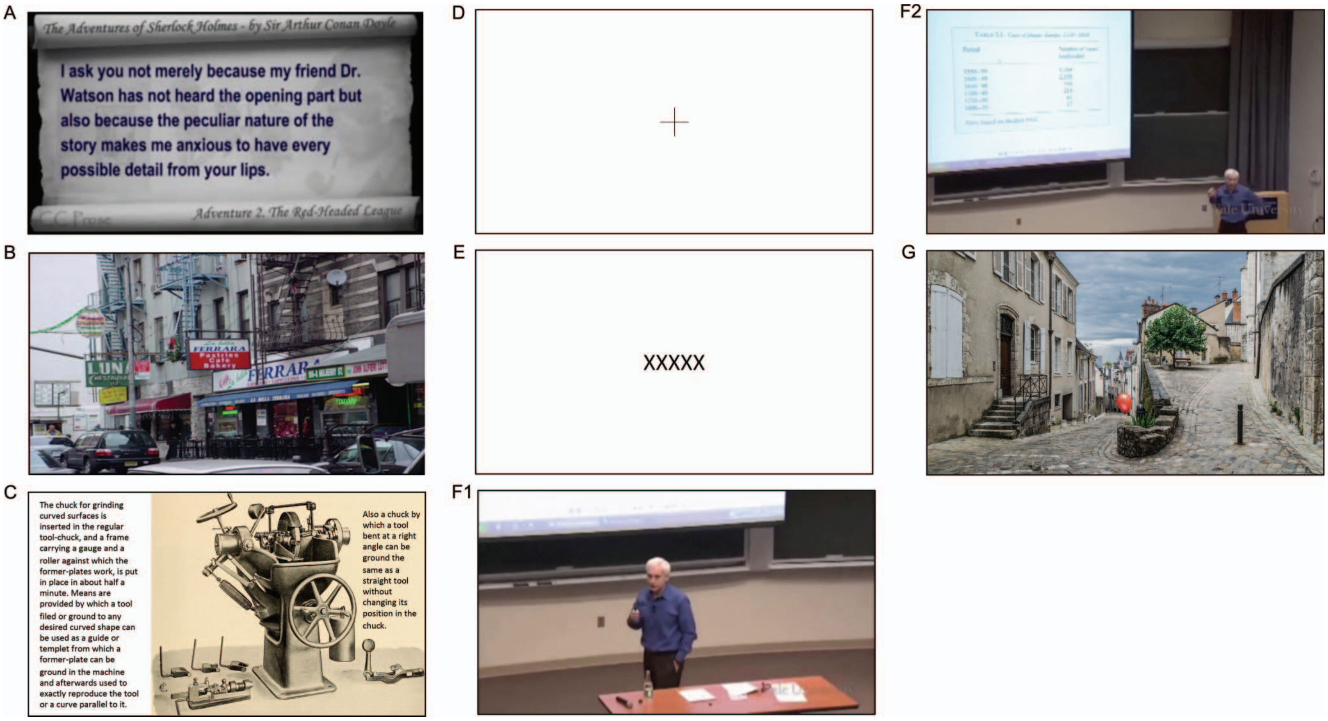

Figure 1. Example stimuli for (A) reading, (B) scenes, (C) illustrated text, (D) audiobook, (E) sustained attention to respond task (SART), (F1) lecture (lecturer only), (F2) lecture (with lecture material on screen), and (G) film. The images displayed here for Illustrated text and Film were taken from Wikimedia Commons, an online repository of free-use content images, to provide an illustration of the display. For Illustrated texts used in the actual experiment, see The Way Things Work (Macaulay, 1988). For the Film, see The Red Balloon (Lamorisse, 1956). See the online article for the color version of this figure.

book task, we explored how mind-wandering-based gaze behaviors would vary across tasks with similar central spatial allocation and low visual processing demands but with different discourse processing demands.

Lecture. We included a lecture comprehension task (lecture), which encouraged central spatial allocation (on the lecturer, see Figure 1, Panel F1; or on lecture material, see Figure 1, Panel F2) and required both high visual processing (lecture diagrams) and discourse processing (written and auditory presentation of lecture materials). Motion has a tendency to capture gaze (e.g., Mital, Smith, Hill, & Henderson, 2011), but in the lecture task, remaining fixated on the moving lecturer was not necessarily helpful—and perhaps even harmful (Wilson et al., 2018)—for comprehension of the learning material that was presented auditorily. This provided a particularly interesting comparison with the audiobook task given the stark differences in visual processing demands of these two tasks and with the reading task given the variation in spatial allocation demands.

Film. Watching film is unique compared with other tasks in that filmmakers intentionally manipulate the stream of low-level visual input in their films, such as motion, luminance, image framing, and others, to direct attention and gaze in calculated ways (Dorr, Martinetz, Gegenfurtner, & Barth, 2010; Mital et al., 2011; Wang, Freeman, Merriam, Hasson, & Heeger, 2012). This is sometimes referred to as the tyranny of film (Loschky, Larson, Magliano, & Smith, 2015). Therefore, the film task offered unique insights into the relationship between mind wandering and gaze insofar that any mind-wandering-based gaze behaviors would indicate how the visual system deviates from the film's visual design. The film task also required a certain degree of discourse processing, albeit potentially less than the tasks, such as the reading, illustrated text, lecture, and audiobook tasks.

Experimental Design

We asked participants ($N = 132$) to complete the battery of cognitive tasks while we tracked their gaze. We measured mind wandering by asking participants to respond to pseudo-randomly distributed thought probes that prompted participants to report whether they were attentive to the task or mind wandering at a given moment (Smallwood & Schooler, 2006). Our analyses focused on content-independent gaze behaviors (number of fixations, fixation duration, fixation dispersion, and saccade amplitude) because these are more likely to generalize across tasks than content-dependent behaviors that are, by definition, specific to the task content (e.g., whether people look at salient portion of the screen, whether word characteristics influence gaze durations). The number and duration of fixations offered particularly interesting theoretical insights because these two related gaze behaviors are frequently among discussions of mind-wandering-based gaze behaviors in reading (Bixler et al., 2015; Foulsham et al., 2013; Frank et al., 2015; Reichle et al., 2010), scene viewing (Krasich et al., 2018), lecture viewing (Hutt, Hardey, et al., 2017), and film viewing (Mills et al., 2016). If mind-wandering-based modulations of these content-independent gaze behaviors generalized across tasks with similar processing demands and affordances, this would provide evidence for the task resemblance hypothesis. If mind-wandering-based gaze behaviors generalized across all tasks regardless of processing demands, this would refute our hypothesis and provide evidence for a single set of mind-wandering-based gaze behaviors. If no patterns emerged, findings would suggest that mind-wandering-based gaze behaviors are entirely dependent on the specific task and context despite similarities that may exist across tasks.

We tracked gaze using two different eye tracking systems—a research-grade eye tracking setup and a consumer off-the-shelf (COTS) eye tracking setup—which allowed us to account for potential instrument-specific differences in measuring gaze behaviors across previous studies. This addresses the possibility that differences in mind-wandering-based gaze behaviors across different empirical studies are confounded by differences in experimental set up. For instance, the sampling rate of COTS eye trackers is much lower than that of research-grade eye trackers (e.g., in the order of 60 Hz vs. 2,000 Hz) and is used without head mounts. Although this boasts a degree of ecological validity, data quality is compromised, and samples can be lost due to movement. Low sampling rates and lost data may especially influence how gaze behaviors, such as fixations and saccades, are defined, even though COTS eye trackers have previously been positively evaluated in the context of monitoring the eye movement parameters that we measure here (e.g., Gibaldi, Vanegas, Bex, & Maiello, 2017). It is therefore important to understand this trade-off when assessing the relationship between gaze and mind wandering and to assess how mind-wandering-based gaze behaviors can generalize across experimental setups.

Altogether, our work explores theoretically motivated questions regarding the nature of mind-wandering-based gaze behaviors considering the process by which the visual system allocates gaze. Our work offers insights into the growing heterogeneity in the literature with regard to the existence of a single set of mind-wandering-based gaze behaviors, unveiling commonalities in processing demands that yield similar patterns of mind-wandering-based gaze behaviors.

Method

Participants

We recruited 136 participants from a private Midwestern U.S. university (age: $M = 19.8$ years, $SD = 1.51$ years; 74% female; ethnicity: 4.48% African American/Black, 8.96% Asian, 73.1% Caucasian/White, 9.70% Hispanic, Latino, or Mexican origin, 3.73% other ethnicities). From this group, 94 participants performed the experiment on a laptop with a consumer-grade off-the-shelf Tobii EyeX eye tracker (Tobii, Stockholm, Sweden), whereas 42 participants performed it on a desktop computer with a research-grade Eyelink 2k tower-mounted eye tracking system (SR Research, Ontario, Canada). We recruited fewer participants for the Eyelink setup as gaze data collected using a research-grade eye tracker was expected to be less noisy compared with the Tobii EyeX setup. The four participants who experienced calibration failures on the Tobii system were excluded from the dataset.

Participants received course credit or financial compensation ($15/hr) for their participation. Informed consent was obtained from each participant, and participants signed a voluntary data release form. All procedures and materials were approved by the university's institutional review board.

Power Analyses

Our sample size was primarily determined by a commitment to test as many participants as possible prior to the eye tracking equipment moving to new facilities. This decision was partially motivated by the fact that few studies have investigated gaze correlates of mind wandering outside of reading tasks, thus, limiting our ability to select an effect size for an a priori power analysis. Additionally, because we predict that effect sizes should vary by task, we did not find it suitable to rely on effects from reading-dominated studies to estimate sample sizes for nonreading tasks. Instead, we used Monte Carlo simulations to estimate the minimum detectable effect sizes (MDES) from our data. Because the power calculations are closely related to our data and statistical models, we describe these analyses below (see the Mind Wandering and Eye Gaze Across Tasks section).

Stimuli and Apparatus

The stimuli varied across a battery of seven tasks, which included the following: (1) reading a computer-paced narrative story, (2) viewing visual scenes for a later memory test, (3) comprehending an illustrated text, (4) listening to an audiobook, (5) performing a SART task, (6) viewing and comprehending a recorded video lecture, and (7) viewing and understanding a narrative film.[1] Completing these tasks did not require any overt responding (i.e., a key or mouse press) to avoid eye movement artifacts (e.g., looking down at the keyboard) that are possible with making these responses. In doing so, we avoided confounding eye movements associated with *vision for perception* (i.e., processing to obtain visual features) and those related to *vision for action* (i.e., processing to guide movements; e.g., Milner & Goodale, 1993). These two types of vision have been attributed to distinct visual processing streams in the brain, which operate on different time scales and may be influenced differentially by mind wandering. The specific stimuli for each task are illustrated and described in the following text. We administered task-specific posttest assessments after participants completed the battery, and the items for this test are also described subsequently.

Eye movements were recorded either using a research-grade Eyelink 2k tower-mounted eye tracking system (42 participants), or with a remote, consumer-grade off-the-shelf Tobii EyeX eye tracker (90 participants). For the Eyelink system, we used a chin and forehead rest to maintain a viewing distance of 57 cm. Eye movements were sampled at a rate of 1,000 Hz. The eye tracker was calibrated using a nine-point calibration at the beginning of the experiment. Drift correction (one-point recalibration) was conducted after each mind wandering probe to correct for drift in the

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[1] Data for the scene task were collected with the Eyelink Eye Tracker were previously included in Krasich et al., 2018.

eye tracking signal that can occur naturally over time. Stimuli were presented on a CRT monitor with a resolution of 1680 pixels × 1050 pixels that subtended 47.2° visual angle horizontally and 29.5° vertically. For the Tobii EyeX system, participants performed the experiment on a 15-in. laptop (screen resolution: 1600 pixels × 900 pixels) with the eye tracker positioned directly under the screen using a magnetic strip (according to guidelines provided by Tobii). They were asked to sit comfortably with their chair pulled up to the desk, but their head or body movements were not restricted in any way. Before calibration, they were familiarized with the equipment and given the following instructions:

> The white dots that appear on the screen are your eyes. Try to position yourself so that your eyes are in the middle of the black box [centrally presented to ensure that the starting position for calibration is correct]. Make sure you are comfortable and sitting just like you normally would.

The Tobii EyeX system sampled eye movements at a rate of approximately 60 Hz. The eye tracker was calibrated using an in-house, 60-s calibration procedure at the beginning and end of the experiment. For the first 32 participants, recalibration occurred after each task, but this step was skipped for the remainder of the participants to keep the experiment at a reasonable length (about 1 hr). The calibration process entailed the consecutive presentation of five calibration points, beginning in the center and proceeding clockwise from the upper right corner of the screen. Calibration points consisted of a black dot surrounded by a white circle that smoothly expands and contracts over a period of 5 s. There were three participants who experienced calibration errors during testing and, thus, a total of six tasks were missing for these participants (one, two, and three tasks, respectively).

Task Battery

Participants completed a battery of seven tasks, which are further detailed in the following text. Each task ended after 6 min when the next task automatically began.

Reading. Participants read an excerpt from the narrative story *The Red-Headed League* by Sir Arthur Conan Doyle. The text was presented on the screen one sentence at the time based on the pacing of a read-along audiobook (Kopp & D'Mello, 2016). The text consisted of 43 sentences (932 words in total), presented on 35 sequential pages (slides), thus each page contained two to five lines of text. Because sentence length varied, the dimensions of the display area devoted to the story ranged from a minimum 32.3° horizontally × 4.2° vertically to a maximum of 38.5° horizontally × 12.6° vertically.[2] The instructions for the reading task were as follows: "In the following activity, you will be reading an excerpt from a book. You do not need to use the keyboard or mouse. The pages will advance automatically. Your task is to read the text to understand the plot." In the posttest, participants answered six multiple choice questions about the text (e.g., Mr. Wilson pulled out of his pocket. . . [1] a small metal ornament, [2] a pen, [3] a box of snuff, [4] a newspaper [correct answer]).

Scenes. Participants were presented with six images of urban scenes—each image subtending 47.2° horizontally × 26.6° vertically—used in previous scene perception research (Krasich et al., 2018) for 60 s each. Krasich et al. (2018) showed that mind-wandering-based changes in gaze behavior were observed as early as 25 s prior to a mind wandering report. The 60-s presentation allowed for each scene to be viewed for an equal amount of time within the 6-min task, and changes of behaviors associated with mind wandering could be investigated over time. This relatively long presentation time is appropriate given the fact that gaze is typically distributed broadly at first to extract the spatial layout of the scene (e.g., Karpov, Luria, & Yarbuss, 1968) before shifting to focal processing that is apt for object identification (e.g., Antes, 1974). Moreover, rapid stimulus changes may reduce the rate of mind wandering and, thus, would likely require a task longer than 6 min to make high-powered comparisons across reports of attentive viewing and mind wandering. Instructions for the scene viewing task were as follows: "In the following activity, you will study pictures of urban scenes. Your task is to study each picture carefully and try to remember as much detail as possible." In the posttest, participants saw six scene vignettes that were extracted from a random 200 pixel × 200 pixel portion of three studied images and three unstudied foil images, which were used in past research (Krasich et al., 2018). Participants were asked whether each vignette was part of a scene that they previously studied.

Illustrated texts. These stimuli consisted of two illustrated text (3-min each) on everyday devices (electric bell, cylinder lock) from the book *The Way Things Work* (Macaulay, 1988), accompanied by a breakdown scenario (e.g., an illustrated text of an electric bell, with a scenario where the bell gives a short "ding" even though the button is pressed continuously; D'Mello & Graesser, 2014). These stimuli subtended 47.2° horizontally × 26.6° vertically. Instructions were as follows: "In the following activity, you will be reading an illustrated text on how an everyday device works. Your task is to read the illustrated text to understand how the device works." In the posttest, participants answered six multiple choice questions (three per device) about the devices (e.g., What is the first event that occurs when the button is pressed? [1] The armature moves to the electromagnet, [2] The contacts are closed [correct answer], [3] The spring compresses).

Audiobook. Participants were asked to fixate on a central fixation cross (subtending 3.1° both horizontally and vertically) while listening to an excerpt from the beginning of the book *Walden* by Henry Thoreau (1854). The text consisted of 25 sentences (835 words in total). Instructions were as follows:

> In the following activity, you will be listening to an audio book. There will be a fixation cross on the screen. Your task is to listen to the story and understand the main message while keeping your eyes focused on the fixation cross.

In the posttest, participants answered six multiple choice text base (Kintsch, 1988) comprehension questions (e.g., According to the author, the book was particularly addressed to [1] young townsmen, [2] poor students [correct answer], [3] inhabitants of New England, [4] his kindred).

SART. Participants were presented with a sequence of "XXXXX" (subtending 7.2° horizontally × 1.7° vertically) and "OOOOO" (subtending 9.1° horizontally × 1.7° vertically) on the

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[2] All stimulus measurements are based on the apparatus and viewing conditions associated with the Eyelink Eye Tracker with which viewing distance was constrained. For the Tobii EyeX, the same stimuli were scaled to the smaller display.

screen. The sequence was parsed such that each letter string was visible for 2 s on the screen followed by a 2-s interstimulus interval. This version of the SART was based on previous work (Smallwood et al., 2006) and contained 20% targets ("OOOOO") that occurred pseudorandomly (same order for all participants). Instructions were as follows:

> In the following activity, you will be doing an attention task. Your task is to focus on the screen and imagine pressing a button each time you see "OOOOO." Please do not press any actual buttons on the key board. Also, try to count the number of times you see "OOOOO" as you will be asked about this later on.

At the end of the experiment, participants were asked to report the number of times they saw "OOOOO" as part of the posttest assessment. Participants viewed 90 letter strings in total.

Lecture. Participants watched the first 6 min of an actual video lecture on population growth (Hutt, Hardey, et al., 2017; Wyman, 2012). The video subtended 47.2° horizontally × 26.6° vertically. Instructions were as follows: "In the following activity, you will be watching a lecture on population growth. Your task is to watch the lecture to learn about population growth." In the posttest, participants answered six multiple choice questions about the lecture (e.g., latrines or public washrooms, were found . . . [1] in ditches in the middle of streets [correct answer], [2] in church basements, [3] in forested areas outside the city walls, [4] in a well-like hole within the house).

Film. Participants watched the first 6 mins of the narrative film *The Red Balloon* (Lamorisse, 1956), which has been previously used in mind wandering research (Faber & D'Mello, 2018; Faber, Radvansky, & D'Mello, 2018; Mills et al., 2016). The film subtended 47.2° horizontally × 26.6° vertically. Instructions were as follows: "In the following activity, you will be watching an excerpt from an old French movie. Your task is to watch the movie and understand the plot." In the posttest, participants saw six still frames extracted from the film (three actual and three previously unseen still frames) and were asked whether they had seen each frame in the excerpt of the film.

Procedure

Participants were asked to leave cell phones and watches outside of the testing room. Upon providing written consent, participants received verbal instructions about the procedure and eye tracker calibration process. For the remote Tobii EyeX eye tracker, participants received additional instruction to make sure that they were seated in an upright, comfortable position to avoid loss of eye tracking signal. After calibration, participants received written instructions about the main experiment, which consisted of seven tasks (stimulus clips) presented in pseudorandom order for 6 min each, followed by a posttest at the end of the experiment. Thought probes to measure mind wandering were presented at pseudorandom intervals of 90 s to 120 s, resulting in three thought probes during each task. This frequency is similar to previous mind wandering research (e.g., Weinstein, De Lima, & Van der Zee, 2018). Prior to the task, participants received instructions to report mind wandering ("zoning out") whenever they found themselves thinking out something else altogether when they received a thought probe (see Appendix A for full instructions). After the main experiment, participants completed the posttest (order of tasks pseudorandom), filled out a brief questionnaire on their subjective perceptions of the tasks (not analyzed here), and provided demographic information including age and gender.

Gaze Feature Computation

We computed gaze parameters for 15-s and 25-s windows preceding each mind wandering probe. These window sizes were motivated by previous work. Specifically, in the context of scene viewing, the global gaze correlates of mind wandering were most robust in the 15 s preceding a mind wandering self-report (to a thought probe), although differences in the number of fixations were detectable as early as 20 s and 25 s prior to the report (Krasich et al., 2018). Similarly, in previous machine learning approaches in the context of reading, gaze parameters computed for longer windows (12 s) were more predictive than those computed for shorter 4-s to 10-s windows (Bixler et al., 2015; Bixler & D'Mello, 2015; Faber et al., 2018). In the context of interacting with an intelligent tutoring system, lecture comprehension, and narrative film comprehension, even longer window sizes of 18–30 s performed optimally (Hutt et al., 2016; Hutt, Hardey, et al., 2017; Hutt, Mills, et al., 2017; Mills et al., 2016). Thus, our 15 s and 25 s window sizes were selected to accommodate these relevant time scales. Fixations were assigned to the time window in which the majority of the fixation duration occurred.

For data recorded with the Eyelink system, we used the fixations reported in the SR Research output file. Saccades were defined as changes in recorded fixation position that exceeded 0.2° with either a velocity that exceeded 30°/s or an acceleration that exceeded 9,500°/s^2 using software provide by SR Research. From these, we computed the number of fixations, mean fixation duration and mean saccade amplitude by averaging across fixations and saccades in each time window. Fixation dispersion was computed as the root mean square of the distance from each fixation to the average position of all fixations (Holmqvist et al., 2011; Euclidean distance).

Data recorded with the Tobii EyeX system were first segmented into fixations and saccades using Open Gaze and Mouse Analyzer, an open source package for analyzing eye tracking data (Vosskühler, Nordmeier, Kuchinke, & Jacobs, 2008). Fixations were defined as consecutive gaze points within a range of 57 pixels (approximately 1 degree of visual angle when the distance from the screen is approximately 60 cm) for longer than 100 ms, which is the shortest duration for reliable fixations during naturalistic reading, as shorter durations are likely artifactual and are less likely to involve information processing (Holmqvist et al., 2011; Reichle, Pollatsek, Fisher, & Rayner, 1998). Saccade parameters were computed from the time and distance between two consecutive fixations. From these, our four gaze features were computed as defined in the preceding text.

Results

Rates of Mind Wandering Across Tasks and Eye Trackers

Out of the 2,754 total delivered thought probes, on average, participants reported mind wandering around half of the time (50.97% of response to probes, *SD* = 34.95%). This rate is within the range of rates typically observed in laboratory and field-based research of mind wandering (Killingsworth & Gilbert, 2010; Seli et al., 2018; Smallwood & Schooler, 2015). Although not central to our main research question, it is important to first understand the frequency of reported mind wandering across tasks and eye tracking setups (Table 2). We used the *lme4* package in R (Bates, Mächler, Bolker, & Walker, 2015) to conduct a mixed-effect logistic regression analysis that modeled mind wandering (yes or no response to the probe) as a task (seven levels, with audiobook as the reference group) by eye tracker (two levels with Tobii EyeX as the reference group) interaction with participant as a random factor (random intercept only). We also included task order as a continuous covariate to account for fatigue effects. Significance testing was conducted using two-tailed tests with alpha set to .05, and Wald's chi-square and *p* values are reported using the *car* package (Fox, 2015; Fox & Weisberg, 2018) to test the significance of main effects.

The model with the Task × Eye Tracker interaction failed to converge, so we adopted an alternate approach. First, we regressed mind wandering (yes or no response to the probe) on eye tracker and task order with participant as a random intercept. We found that participants had a greater propensity to report mind wandering with the Tobii EyeX setup, $\chi^2(1) = 5.35$, $p = .021$, $B = .38$, $SE = .16$. This difference could be attributable to a number of factors, such as the physical context of the lab and the use of a chin rest. Potentially, it might be easier for participants to move and/or look off-screen in the Tobii EyeX set up (no chin rest), which may have facilitated disengagement from the task. As such, we cannot draw any strong conclusions in these results but need to consider the effect of each eye tracker setup in subsequent analyses. We also found a significant main effect of task order, $\chi^2(1) = 7.50$, $p = .006$, $B = .06$, $SE = .02$, in that mind wandering increased as the study progresses. As such, task order is also considered as a covariate in subsequent analyses.

We next investigated mind wandering rates across tasks using mixed-effect logistic regression analyses to model mind wandering (yes or no response to the probe) with task (seven levels with audiobook as the reference group) as a fixed-effect factor, task order as a covariate, and *participant* as a random intercept. Because mind wandering varied across eye trackers, we conducted these analyses separately for each eye tracker, although the pattern of results across eye trackers were similar. We found that mind wandering varied across tasks for both the Tobii EyeX setup, $\chi^2(6) = 173.01$, $p < .001$, and the Eyelink setup, $\chi^2(6) = 69.02$, $p < .001$. Pairwise comparisons were conducted using the *emmeans* package in R (Lenth, 2018) using the FDR adjustment for multiple comparisons (Benjamini & Hochberg, 1995).

Results are illustrated in Figure 2. For the Tobii EyeX setup, we found the following pattern in the data with respect to increasing amounts of mind wandering: Film < Reading < Lecture = Illustrated Texts < Scenes = SART = Audiobook. The pattern was somewhat different for the Eyelink setup: Film = Illustrated Text < Lecture = Reading = Scenes < Audiobook = SART (with the exception that the adjusted *p* for the Illustrated Text and Lecture comparison was .19). These somewhat different patterns reiterate the importance of covarying eye tracker setup for subsequent analyses. Across both setups, though, mind wandering was most frequent in the Audiobook and SART tasks and least frequent in the Film viewing task.

The frequency of mind wandering was validated by showing that mind wandering was negatively related to task performance, which is what we expected given the tasks we used here (Randall, Oswald, & Beier, 2014). These results are reported in Appendix B.

Mind Wandering and Eye Gaze Across Tasks

To address our main research question, we assessed gaze behavior associated with self-reports of mind wandering across tasks. First, we computed the number of fixations, mean fixation duration, mean fixation dispersion, and mean saccade amplitude across 15-s and 25-s time windows before probe onset. We then *z*-scored normalized each gaze parameter by eye tracker. To assess the relationship between mind wandering and gaze behavior, we conducted mixed-effect linear regression analyses that individually modeled each gaze parameter on a mind wandering (yes or no [reference group]) by task (audiobook as the reference group) interaction with participant as a random factor (intercept only). Task order was included as continuous covariate to account for fatigue effects and probe number (three levels with the first probe as the reference group) was included as a fixed-effect covariate to account for novelty effects. Eye tracker setup (two levels with the Eyelink setup as the reference group) was also included as a fixed-effect covariate to account for any possible changes in eye movements due to tracker set-up and differences in established fixation parameters. Models were computed for the 15-s and 25-s windows separately, as data are not independent (i.e., 25-s windows include 15-s window data). Thus, there were eight models in all (4 Gaze Parameters × 2 Window Lengths). We used Type II

Table 2
Percentages (Standard Deviations in Parentheses) of Mind Wandering Reports Across Tasks (Averaged Across Participants)

Task	Tobii EyeX	Eyelink eye tracker	Both eye trackers
Reading	40.07% (34.88%)	45.53% (37.09%)	41.79% (35.54%)
Scenes	64.04% (31.47%)	46.34% (33.23%)	58.46% (32.96%)
Illustrated text	54.92% (31.58%)	32.52% (32.90%)	47.80% (33.55%)
Audiobook	70.41% (28.62%)	63.49% (28.33%)	68.19% (28.60%)
SART	67.42% (31.77%)	64.10% (33.67%)	66.41% (32.27%)
Lecture	50.56% (31.43%)	39.02% (29.72%)	46.92% (31.25%)
Film	26.97% (31.33%)	27.50% (33.66%)	27.13% (31.94%)
Mean	53.48% (34.69%)	45.50% (34.94%)	50.97% (34.95%)

Note. SART = sustained attention to response task.

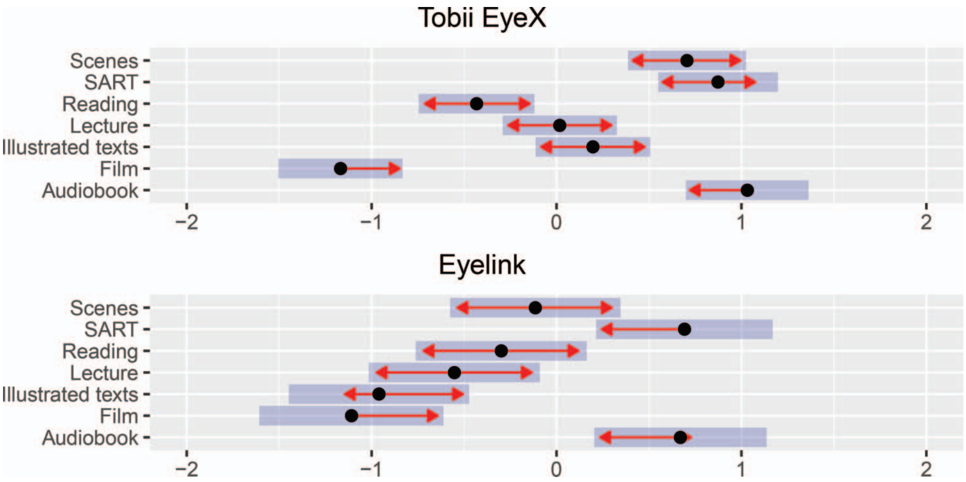

Figure 2. Pairwise comparisons assessing mind wandering rates across tasks for each eye tracking set up. Comparisons are FDR-corrected for multiple comparisons. SART = sustained attention to response task. See the online article for the color version of this figure.

sum of squares to investigate the main effects of mind wandering controlling for covariates. In the presence of a significant Mind Wandering × Task interaction, only the interaction is reported and interpreted in lieu of main effects. Unstandardized coefficients for the effect of mind wandering on each gaze parameter are reported in Table 3 whereas coefficients for each predictor variables included in the models are presented in Appendix C (15-s time window) and Appendix D (25-s time window).

MDES. It is prudent to examine the minimum detectable effect sizes prior to considering the results. For each task, this involved estimating the effect of mind wandering (yes or no) on each gaze feature (number of fixations, fixation duration, fixation dispersion, and saccade amplitude) net of the aforementioned covariates in a mixed effects regression model. Thus, the coefficient of the mind-wandering fixed effect served as our effect size measure. Because the dependent variables were *z*-score standardized and mind wandering was measured as a binary variable, the magnitude of the coefficient reflects the changes in the pertinent gaze feature in standard deviation units associated with mind wandering (coded as 1) compared with paying attention (coded as 0). Accordingly, using the *simr* package (Green & MacLeod, 2016), we conducted 28 power analyses (using data as measured within 15 s prior to probe onset) to estimate the MDES for mind wandering on each of the four gaze features for each of our seven tasks. For each analysis, we estimated power associated with effect sizes ranging from .05 to .55 in increments of .05 after setting alpha to .05 and the number of simulations to 1,000. We retained the lowest effect size that would yield a power of .8. As expected, the MDES varied by task and feature with a mean of .25, a range of .05 to .45, and interquartile range of .20 to .30. The specific MDES associated with each task and gaze feature are included

Table 3

Unstandardized Coefficients (B; Standard Errors in Parentheses) Reporting the Main Effect of Mind Wandering on Gaze Parameters Across Tasks

Task	Time window	Number of fixations	Fixation durations	Fixation dispersion	Saccade amplitude
Reading	15 s	−.30 (.07)***	.08 (.09)	.24 (.11)*	−.14 (.08)†
	25 s	−.28 (.06)***	.08 (.10)	.21 (.11)*	−.18 (.07)*
Scenes	15 s	−.29 (.07)***	.17 (.09)†	.15 (.11)	−.12 (.08)
	25 s	−.26 (.06)***	.12 (.09)	.01 (.10)	−.04 (.07)
Illustrated texts	15 s	−.58 (.07)***	.18 (.09)†	.24 (.11)*	−.01 (.08)
	25 s	−.56 (.06)***	.20 (.09)*	.09 (.11)	−.01 (.07)
Audiobook	15 s	.05 (.07)	−.29 (.10)**	.14 (.12)	.08 (.09)
	25 s	.08 (.07)	−.43 (.10)***	.18 (.11)†	.07 (.08)
SART	15 s	−.01 (.07)	−.23 (.10)*	.09 (.11)	.19 (.09)*
	25 s	.002 (.07)	−.28 (.10)**	.18 (.11)†	.17 (.08)*
Lecture	15 s	−.07 (.07)	−.12 (.09)	.02 (.10)	.26 (.08)**
	25 s	−.07 (.06)	−.05 (.09)	−.02 (.10)	.14 (.07)*
Film	15 s	−.04 (.08)	−.08 (.10)	.18 (.12)	.01 (.09)
	25 s	−.05 (.07)	−.05 (.10)	.03 (.12)	.04 (.08)

Note. SART = sustained attention to response task.
$^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

in Appendix E and should be considered in interpreting the effects presented in Table 3.

Number of fixations. Mind wandering was a significant predictor of the number of fixations at both the 15-s and 25-s time windows, but this effect varied across tasks, as indicated by a significant mind wandering by task interaction at both the 15 s, $\chi^2(6) = 64.99$, $p < .001$, and 25 s, $\chi^2(6) = 68.45$, $p < .001$, time windows. Post hoc comparisons across tasks showed that regardless of time window, reports of mind wandering were associated with fewer fixations compared with reports of paying attention for the reading, illustrated text, and scenes tasks. The number of fixations did not vary by mind wandering in the audiobook, SART, lecture and film tasks.

Fixation durations. Mind wandering was a significant predictor of fixation duration at both time windows, and this effect varied across tasks as indicated by a significant mind wandering by task interaction at the 15 s, $\chi^2(6) = 23.49$, $p < .001$, and 25 s, $\chi^2(6) = 33.55$, $p < .001$, time window. We found that reports of mind wandering were associated with shorter fixation durations in the audiobook and SART tasks, whereas fixations durations were longer in the illustrated text task. Fixation durations associated with mind wandering tended to be longer in the scenes task, but findings were not significant. Fixation durations did not vary with mind wandering in the lecture, reading, or film tasks.

Fixation dispersion. Mind wandering was a significant predictor of fixation dispersion measured within the 15-s time window, $\chi^2(1) = 12.58$, $p < .001$, $B = .14$, $SE = .12$, and the 25-s time window, $\chi^2(1) = 5.19$, $p = .022$, $B = .18$, $SE = .11$. This effect did not vary across tasks, as indicated by a nonsignificant mind wandering by task interaction within the 15-s time window, $\chi^2(6) = 3.39$, $p = .759$, or the 25 s time window, $\chi^2(6) = 4.78$, $p = .573$. This finding indicates that reports of mind wandering were associated with greater fixation dispersion compared with reports of paying attention across all tasks.

Saccade amplitude. There was no overall main effect of mind wandering as measured within both a 15-s and 25-s time window before probe onset, but there was a significant mind wandering by task interaction as measured by the 15-s time window, $\chi^2(6) = 20.95$, $p = .002$, and the 25-s time window, $\chi^2(6) = 15.44$, $p = .017$. We found that mind wandering was associated with larger saccade amplitude compared with reports of paying attention for the SART and lecture tasks for both time windows. Conversely, saccade amplitude was smaller compared with reports of paying attention in the reading task but only when measured within the 25-s time window. There were no significant differences for the other tasks: Saccade amplitude did not vary with mind wandering in the audiobook, scenes, illustrated texts, or film tasks.

Patterns in Mind-Wandering-Based Gaze Behaviors Across Tasks

Following the task-resemblance hypothesis, mind-wandering-based gaze behaviors should be similar across tasks with similar task demands. We next discuss mind-wandering-based gaze behaviors for tasks that shared and/or varied across spatial allocation, visual processing, and discourse processing demands. These findings are summarized in Table 4.

Tasks with extensive spatial allocation demands. Mind wandering was associated with fewer, more dispersed fixations as well as shorter saccades in the reading task. Fixation durations associated with mind wandering were also longer, but findings were not significant. These observations provide interesting insights when compared with other tasks with extensive spatial allocation demands. Specifically, mind wandering was also associated with fewer fixations in the scenes task—which had similar visual processing, but lower discourse processing demands than the reading task. Similarly, mind wandering was associated with fewer, longer, and more dispersed fixations in the illustrated text task—which had equally high visual and discourse processing demands as the reading task. Mind wandering was not associated with changes in saccade amplitude in the scenes and illustrated text tasks. These findings suggest that mind-wandering-based fixation patterns may generalize across tasks with extensive spatial allocation and high visual processing demands, in favor of the task-resemblance hypothesis. These ideas are further elaborated and interpreted in the Discussion section.

Tasks with central spatial allocation demands. If spatial allocation demands impact the relationship between mind wandering and fixation patterns then, following the task-resemblance hypothesis, mind-wandering-based gaze behaviors should vary across tasks with extensive and central spatial allocation demands. Accordingly, mind wandering was associated with shorter (as opposed to longer) fixations in the audiobook and SART tasks, although there were no other significant fixation patterns associated with mind wandering in these tasks. This suggests that, although fixation patterns were reliable indicators of mind wandering in tasks with extensive spatial allocation demands, this observation did not hold in tasks with central spatial allocation

Table 4

A Summary of Gaze Behaviors Associated With Mind Wandering Collapsed Across Time

Spatial allocation	Visual processing	Discourse processing	Task	Number of fixations	Fixation durations	Fixation dispersion	Saccade amplitude
Extensive	High	High	Reading	↓		↑	
		Low	Scenes	↓			↓
		High	Illustrated text	↓	↑	↑	
Central	Low	High	Audiobook		↓		
		Low	SART		↓		↑
	High	High	Lecture				↑
		Low	Film				

Note. The arrows indicate whether gaze behaviors increased (up arrow) or decreased (down arrow) with reports of mind wandering compared with paying attention. SART = sustained attention to response task.

demands. Mind wandering was associated with an increase in saccade amplitude in the SART and lecture task. Moreover, this relationship between mind wandering and saccade amplitude was reversed in these tasks compared with the reading task, which had extensive spatial allocation demands. This provides further evidence in favor of the task-resemblance hypothesis.

There were no gaze behaviors associated with mind wandering in the film task. It is possible that because filmmakers strategically manipulate visual information to direct viewers' attention (Loschky et al., 2015), global gaze behaviors are insufficient for reflecting changes due to mind wandering. Patterns in mind-wandering-based gaze behaviors across tasks are further interpreted in the Discussion section.

The Relationship Between Gaze Parameters

Although we modeled each gaze parameter separately, it is important to consider that many gaze parameters are correlated. To better understand the relationship between gaze parameters, we used Pearson correlations to correlate each gaze parameter (z-scored normalized) separately for each time window (as data are not independent), collapsing across eye tracker (which was not a significant predictor of gaze in any of the regression models). Findings are reported in Table 5, and show that, indeed, gaze parameters were moderately correlated with two exceptions. Specifically, fixation dispersion was weakly correlated with fixation duration and not correlated with saccade amplitude. These findings are relevant because fixation duration has been used to predict subsequent fixation location (Tatler et al., 2017), and findings here further support the link between the temporal and spatial aspects of gaze that are frequently considered separately in many frameworks of gaze control (e.g., Borji & Itti, 2013; Findlay & Walker, 1999; Nuthmann et al., 2010). That said, fixation dispersion and saccade amplitude, the spatial gaze parameters we measured here, were unrelated to each other, indicating that each parameter uniquely characterized the spatial aspects of gaze control and their relationship to mind wandering across tasks. Also note that although intuitively, for a fixed window, fixation durations should become longer when there are fewer fixations, we found only a moderate correlation, suggesting that there might be other factors influencing fixation duration and/or noise in our measurement. These factors might obfuscate a potential relationship between mind wandering and fixation duration.

Table 5
Pearson Correlation Coefficients Assessing the Relationship Between Gaze Parameters

Gaze parameter	Time window	Fixation durations	Fixation dispersion	Saccade amplitude
Number of fixations	15 s	−.45***	−.35***	.46***
	25 s	−.45***	−.32***	.48***
Fixation duration	15 s		.22***	−.43***
	25 s		.19***	−.41***
Fixation dispersion	15 s			.01
	25 s			−.01

*** $p < .001$.

Discussion

We investigated mind-wandering-based gaze behaviors, as measured by two different eye tracking setups, to gauge whether consistencies across tasks with similar spatial allocation, visual processing, and discourse processing demands would emerge, supporting our task-resemblance hypothesis. We showed that similar mind-wandering-based gaze behaviors emerged for tasks with similar spatial allocation demands (central vs. extensive) and visual processing demands. Moreover, changes in saccade amplitude associated with mind wandering may vary by discourse processing demands. We discuss the specific findings and theoretical implications in the following text.

Mind-Wandering-Based Gaze Behaviors for Tasks With Extensive Spatial Allocation Demands

Fewer fixations were the most consistent gaze correlate of mind wandering in tasks with extensive spatial allocation demands, such as the reading, scenes, and illustrated text tasks. Moreover, the number of fixations were negatively correlated with fixation durations, and, accordingly, mind wandering was numerically associated with longer fixation durations in these tasks, although there was only a significant relationship in the Illustrated text task.[3] One mechanistic explanation for these findings comes from the perceptual decoupling hypothesis (Schooler et al., 2011; Smallwood et al., 2008), which posits that processing for external information is suppressed (although not entirely eliminated) during mind wandering to prioritize internally generated cognition (Bristow, Frith, & Rees, 2005; D'Mello, Kopp, Bixler, & Bosch, 2016; Smilek et al., 2010; Volkmann, Riggs, & Moore, 1980). The efficiency by which the visual system extracts and evaluates external information should likewise be impaired, and fewer and longer fixations may reflect this impairment. That is, it is possible that during mind wandering, the visual system may require more time to assess incoming external information and initiate the next saccade to serve task goals, thereby increasing fixation durations (Krasich et al., 2018). Indeed, in the context of scene viewing tasks, longer fixation durations are frequently observed with low-quality visual input or high cognitive task demands (e.g., Henderson & Choi, 2015; Nuthmann et al., 2010). Accordingly, mind wandering might impair visual processing either by reducing visual (Baird et al., 2014; Kam et al., 2011; Smallwood et al., 2008) and cognitive (Barron et al., 2011) processing of external information or by consuming executive resources (Kane & McVay, 2012; McVay & Kane, 2012).

The current findings further indicate that fewer and longer fixations with mind wandering corresponded with significantly greater fixation dispersion in the reading and illustrated text (15 s only) tasks, although fixation dispersion was numerically larger in the scenes task. Given that fixation durations can predict the subsequent spatial allocation of gaze (e.g., Tatler et al., 2017), it is perhaps not surprising that mind wandering was associated with changes in both temporal (i.e., number and duration of fixations) and spatial (i.e., fixation dispersion) gaze behaviors in these tasks.

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[3] According to the power analysis reported in Appendix E, it is possible that mind wandering might become significantly related to longer fixation durations in the scenes and reading tasks with a larger sample size.

One possibility is that as visual processing slows and becomes sparser (longer and fewer fixations), the visual system allocates fixations more broadly to compensate for the decrease in sampling rate during mind wandering to ensure enough information is sampled to complete task goals (Krasich et al., 2018). This strategic shift, according to our findings, seems influenced by the extent to which a task demands discourse processing. That is, greater discourse processing demands in these tasks were related to greater fixation dispersion. Although the specific mechanism by which the visual system adapts during mind wandering is only speculated here, current findings do indicate a common mechanistic shift in sampling strategy for tasks that demand extensive spatial allocation of the visual field. It is important to note, however, that we did not include a task that demanded extensive spatial allocation but low visual processing, so our comparisons could not discriminate between these task demands here.

Mind wandering was also associated with significantly smaller saccade amplitude in the Reading task (although numerically smaller in the illustrated text and scenes tasks). This finding suggests that saccade amplitude may not be an easily generalizable mind-wandering-based gaze behavior for tasks requiring extensive sampling. It is consistent, however, with the idea that mind-wandering-based gaze behaviors reflect a strategic shift in how the visual system compensates for impaired visual processing. For instance, as previously introduced, saccades during "normal" reading tend to decrease with an increase in text difficulty, thought to reflect the greater processing demands (e.g., Rayner, 1998). Here, we hypothesize that the decrease in saccade amplitude likewise reflects greater discourse processing demands during reading albeit due to the mind-wandering-based reduced visual processing.

Mind-Wandering-Based Gaze Behaviors for Tasks With Central Spatial Allocation Demands

Mind wandering was associated with shorter fixations in tasks with central spatial allocation demands and that demand little in-depth analysis of visual input, such as the SART and audiobook tasks. Still, the relationship between mind wandering and fixation patterns were less robust in tasks with central as opposed to extensive spatial allocation demands. This suggests that fixation patterns may not be reliable indicators of mind wandering in these tasks.

Mind wandering was associated with larger saccades in the SART and lecture tasks. These findings might suggest a greater propensity to scan the visual field during mind wandering in these tasks, although we did not find significantly more dispersed fixations. Following this idea, though, attentional decoupling during mind wandering might increase the likelihood that gaze will likewise wander away from the task-relevant central information as it becomes deprioritized. This idea has been considered before in the context of the exploration-exploitation tradeoff (Jepma & Nieuwenhuis, 2011), which suggests that mind wandering during a stop-signal paradigm is related to an increase in exploratory behavior (Mittner et al., 2014). Important for our main research question and in accordance with our task-resemblance hypothesis, the relationship between mind wandering and saccade amplitude in tasks with central processing demands was reversed from that observed in the Reading task (which had extensive spatial allocation demands).

Gaze Control and Mind Wandering During Film Viewing

We did not observe a relationship between mind wandering and gaze control during the film task, indicating that the global gaze parameters that we measured here did not capture relevant variations in gaze due to mind wandering during this task. Indeed, previous work found that local gaze parameters, such as saccades on and off visually salient objects in the display, were stronger predictors of mind wandering using the same film used in the current work (Mills et al., 2016). This is possibly due to the nature of the film: The stream of low-level visual input—such as filmmakers' manipulation of motion, luminance, image framing, and others—directs gaze to information relevant to the narrative (Dorr et al., 2010; Loschky et al., 2015; Mital et al., 2011; Wang et al., 2012). As such, our findings suggest that future studies should focus on identifying local gaze behaviors when investigating the relationship between mind wandering and gaze control in film comprehension tasks (e.g., Mills et al., 2016).

Gaze Control and Mind Wandering as a Limited Heterogeneous Relationship

Considered together, findings from the current work suggest that the relationship between mind wandering and gaze control is neither specific to the task nor uniform across all tasks, but rather unique for tasks with similar spatial allocation, visual processing, and discourse processing demands. This suggests that the previously observed heterogeneity across studies might be due to idiosyncrasies both within and across tasks, but it is also likely that similarities across tasks have largely been overlooked. Although the specific gaze correlates of mind wandering vary across constellations of tasks, they likely reflect a similar consequence of mind wandering: The deprioritization of external information during mind wandering as predicted by perceptual decoupling.

That said, our work further suggests the importance of considering task-specific idiosyncrasies when assessing the relationship between mind wandering and gaze. For instance, although fixation durations were numerically longer in our reading task prior to a mind wandering report, they did not significantly differ from fixation durations prior to reports of attentive reading. This finding is consistent with accounts that did not find a significant relationship between mind wandering and fixation durations during reading (Smilek et al., 2010; Uzzaman & Joordens, 2011), even though there are studies that have (Foulsham et al., 2013; Frank et al., 2015; Reichle et al., 2010; Steindorf & Rummel, 2019). It is important to note that there are some methodological differences across reading studies that are likely important for understanding these disparities. For instance, Steindorf and Rummel (2019) used fixed sentences rather than temporal windows for computing relative eye movement rates and durations. This means that the length and frequency of fixations could both increase if a sentence is read more slowly, whereas this slowing down could lead to a relative decrease in fixations in a fixed temporal window. Further research in the domain of reading could shed light on the different characteristics of reading tasks that influence mind-wandering-based gaze behaviors.

It is also possible that some parameters display stronger associations when computed across shorter windows, depending on the task (Krasich et al., 2018; Marsman, Renken, Haak, & Cornelissen, 2013; Unema, Pannasch, Joos, & Velichkovsky, 2005), or if only first-fixation during is considered during reading (Steindorf & Rummel, 2019). For instance, a recent study by Krasich et al. (2018) found that mind wandering-related differences in fixation dispersion during scene processing are most prominent in the 5 s to 10 s before to the report. We therefore acknowledge that smaller windows might be appropriate depending on the task, gaze parameters of interest, and eye tracking setup. Specifically, smaller windows might not be suitable for data collected with a COTS eye tracker, as data quality (e.g., missing data, sampling frequency) might limit the stability of gaze parameters computed for these windows.

Our work might also suggest the importance of the relationship between gaze control and mind wandering to have limited heterogeneity. The concept of mind wandering is inherently heterogeneous, as thoughts vary along dimensions of content (e.g., Faber & D'Mello, 2018), intentionality (Seli, Risko, & Smilek, 2016), and progression (Mills, Raffaelli, Irving, Stan, & Christoff, 2018). Furthermore, mind wandering episodes vary in depth (Schad et al., 2012), and in the extent to which people are aware of their mind wandering thoughts (metacognition; Schooler et al., 2011). It is possible that the gaze signatures of mind wandering likewise vary among these dimensions, thus, future work could further investigate whether distinct qualities of mind wandering are uniquely related to differences in gaze control during visual tasks.

Concluding Remarks

In conclusion, we found that the global gaze parameters associated with mind wandering vary across tasks but might be relatively robust for tasks with similar processing demands. Further research into the relationship between mind wandering on gaze parameters in relatively understudied task contexts, such as listening to an audiobook or watching a lecture, is pivotal to gaining a deeper understanding of these relationships. These insights are critical to understanding how mind wandering influences visual information processing across different tasks, a crucial aspect given that most studies in visual cognition assume attentive responding, when in reality, a considerable portion of our waking life is spent mind wandering.

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(*Appendices follow*)

Appendix A

Mind Wandering Report Instructions

Participants received the following instructions about mind wandering:

> This experiment consists of seven blocks, each filled with an activity. At some points during these activities, you may realize that you were thinking about something else altogether. This is called "zoning out." You will be prompted to report whether you are currently zoning out. When you hear a tone play, if you are not zoning out at that moment, press the key marked "No."

If you are zoning out, there are two options:

> If you are thinking about the task itself (e.g., how many pages are there left to read, this video is very interesting) or how the task is making you feel (e.g., curious, annoyed) but not the actual content of the task, please press the key that is labeled "Task".

OR

> 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 labeled "Other." Please familiarize yourself with where these two keys on the keyboard now so that you will know their location when you begin the task.

> Please be as honest as possible about reporting zoning out. It is perfectly natural to zone out. Responding that you were zoning out will in no way affect your performance or your progress in this study, so please be completely honest with your reports. If you have any questions about what you are supposed to do, please ask the experimenter now.

Appendix B

Posttest Performance in Relation to Mind Wandering

Table B1

Average Task Performance Across Eye Tracking Setups (Standard Deviations in Parentheses)

Task	Tobii EyeX	Eyelink	Both eye trackers
SART	1.81 (2.36)	3.42 (6.35)	2.32 (4.11)
Audiobook	.56 (.24)	.58 (.23)	.57 (.24)
Reading	.61 (.27)	.56 (.29)	.59 (.28)
Illustrated text	.61 (.26)	.68 (.21)	.63 (.25)
Scenes	.82 (.18)	.83 (.20)	.82 (.19)
Lecture	.59 (.23)	.60 (.28)	.59 (.24)
Film	.92 (.12)	.90 (.17)	.91 (.14)

Note. Measures represent the proportion of items correct on each posttest (range = 0–1). For the sustained attention to response task (SART), the measure represents the absolute difference from the correct answer (range: 0–32).

It is important to validate that mind wandering was negatively related to task performance, which is what we would expect in the tasks we used here (Randall et al., 2014). We first calculated the proportion of correct responses at the posttest assessment for each task (see Table B1) except for the SART (participants mentally counted the number of times they saw "OOOOO") in which proportion scores could not be calculated, and we instead gauged performance as the absolute difference from the correct answer (range = 0–32). We then conducted a task-level mixed-effect linear regression analysis that modeled posttest performance on the mind wandering rate (percentage of yes responses to the probe per task) by task (with audiobook as the reference group) interaction with *participant* as a random intercept. We included task order and eye tracker as covariates to account for natural forgetting that can occur over time and to control for whether eye tracking setup affected task performance. We excluded the SART from the mixed effects analysis because scores were non-normally distributed (skewed).

We found that mind wandering was associated with worse posttest performance, $\chi^2(1) = 55.92$, $p < .001$, $B = -.002$, $SE = .07$, although this effect varied across tasks, as indicated by a significant mind wandering rate by task interaction, $\chi^2(6) = 14.65$, $p = .012$, but not across eye trackers. $\chi^2(1) = .56$, $p = .454$, $B = .02$, $SE = .02$. To further investigate the interaction between mind wandering rate and task, we recomputed the same model, but separately for each task. We found that mind wandering negatively predicted posttest performance for the audiobook ($B = -.002$, $SE = .001$, $p = .029$), reading ($B = -.003$, $SE = .001$, $p < .001$), illustrated text ($B = -.003$, $SE = .001$, $p < .001$), and lecture ($B = -.001$, $SE = .001$, $p = .044$) tasks, with marginal negative relationships for the scenes ($B = -.001$, $SE = .001$, $p = .065$) and film ($B = -.001$, $SE = .000$, $p = .073$) tasks.

(*Appendices continue*)

To measure the relationship between mind wandering and posttest performance in the SART, we conducted Spearman's rank correlation, but found no relationship ($\rho = .02$, 95% CI [–.15, .21] established through $N = 1{,}000$ bootstraps; $p = .796$).

Together, findings indicate that mind wandering reports were associated with worse posttest performance for each of these visual tasks, except for the SART task. These findings are consistent with the decoupling hypothesis of mind wandering: As attention shifts from processing external information to internally generated cognition, task performance is impaired, as indicated by the negative relationship between mind wandering and performance.

Appendix C

Full Regression Model for 15-s Windows

Table C1

Unstandardized Coefficients (Bs) and Confidence Intervals (CIs) for Variables in the Regression Models Assessing Gaze Control (15-s Time Window Before the Probe)

	Number of fixations		Fixation duration		Fixation dispersion		Saccade amplitude	
Predictor	*B*	CI	*B*	CI	*B*	CI	*B*	CI
Intercept	−.80	[−.99, −.61]	1.23	[1.04, 1.43]	.17	[−.06, .39]	−1.01	[−1.18, −.85]
Mind wandering (MW)	.05	[−.09, .19]	−.29	[−.490, −.10]	.14	[−.09, .37]	.08	[−.10, .25]
Illustrated text (IT)	1.63	[1.49, 1.77]	−1.61	[−1.81, −1.41]	−.34	[−.57, −.11]	1.34	[1.17, 1.52]
Film	.79	[.65, .92]	−1.14	[−1.33, −.95]	−.37	[−.59, −.15]	.94	[.78, 1.11]
Lecture	.63	[.49, .77]	−1.05	[−1.25, −.85]	−.03	[−.26, .20]	1.03	[.85, 1.20]
Reading	2.01	[1.87, 2.15]	−1.68	[−1.87, −1.48]	−.25	[−.48, −.03]	2.14	[1.97, 2.31]
SART	.24	[.08, .40]	−.56	[−.777, −.33]	−.24	[−.49, .02]	.011	[−.19, .21]
Scenes	1.31	[1.16, 1.46]	−1.54	[−1.76, −1.33]	−.28	[−.52, −.04]	1.43	[1.24, 1.61]
Tobii EyeX	.03	[−.15, .20]	−.00	[−.128, .122]	.03	[−.12, .17]	−.02	[−.11, .08]
Trial order	−.04	[−.05, −.03]	−.02	[−.041, −.01]	.01	[−.01, .03]	.01	[−.00, .03]
Probe 2	.08	[.02, .14]	−.06	[−.143, .02]	−.10	[−.19, −.00]	−.02	[−.09, .05]
Probe 3	.02	[−.01, .08]	−.09	[−.168, −.00]	−.06	[−.16, .03]	−.06	[−.13, .01]
MW × IT	−.63	[−.82, −.44]	.47	[.209, .74]	.11	[−.20, .41]	−.09	[−.32, .15]
MW × Film	−.09	[−.29, .12]	.22	[−.061, .50]	.04	[−.28, .36]	−.07	[−.32, .18]
MW × Lecture	−.12	[−.30, .07]	.18	[−.087, .44]	−.12	[−.42, .18]	.19	[−.05, .42]
MW × Reading	−.35	[−.54, −.16]	.38	[.110, .64]	.10	[−.21, .40]	−.22	[−.45, .01]
MW × SART	−.05	[−.25, .14]	.07	[−.202, .34]	−.05	[−.36, .27]	.11	[−.13, .35]
MW × Scenes	−.34	[−.53, −.14]	.46	[.198, .73]	.02	[−.29, .32]	−.20	[−.43, .04]
					Random effects			
σ^2		.41		.70		.88		.52
τ_{00}		$.21_{\text{Participant ID}}$		$.08_{\text{Participant ID}}$		$.11_{\text{Participant ID}}$		$.04_{\text{Participant ID}}$
ICC		$.34_{\text{Participant ID}}$		$.10_{\text{Participant ID}}$		$.11_{\text{Participant ID}}$		$.07_{\text{Participant ID}}$
Observations		2,754		2,454		2,405		2,406
Marginal R^2/Conditional R^2		.39/.59		.23/.31		.02/.13		.44/.48

Note. Variations in sample sizes are due to missing eye tracking data. SART = sustained attention to response task; ICC = intraclass correlation coefficient.

(*Appendices continue*)

Table C2

Test Statistics for Variables in the Regression Models Assessing Gaze Control (15-s Time Window Before the Probe)

	Number of fixations		Fixation duration		Fixation dispersion		Saccade amplitude	
Predictor	$\chi^2(df)$	p	$\chi^2(df)$	p	$\chi^2(df)$	p	$\chi^2(df)$	p
Mind wandering (MW)	44.70 (1)	<.001	.79 (1)	.375	12.58 (1)	<.001	1.31 (1)	.252
Task	2278.32 (6)	<.001	749.32 (6)	<.001	34.91 (6)	<.001	1932.64 (6)	<.001
Eye tracking setup	.09 (1)	.769	.002 (1)	.967	.14 (1)	.712	.128 (1)	.720
Task order	36.04 (1)	<.001	8.03 (1)	.005	1.35 (1)	.245	1.86 (1)	.173
Probe number	7.11 (2)	.029	4.55 (2)	.103	4.36 (2)	.113	2.82 (2)	.244
MW × Task	64.99 (6)	<.001	23.49 (6)	.001	3.39 (6)	.759	20.95 (6)	.002

Appendix D

Full Regression Model for 25-s Windows

Table D1

Unstandardized Coefficients (Bs) and Confidence Intervals (CIs) for Variables in the Regression Models Assessing Gaze Control (25-s Time Window Before the Probe)

	Number of fixations		Fixation duration		Fixation dispersion		Saccade amplitude	
Predictor	B	CI	B	CI	B	CI	B	CI
(Intercept)	−.82	[−1.00, −.64]	1.30	[1.11, 1.49]	.08	[−.13, .30]	−1.13	[−1.29, −.98]
Mind wandering (MW)	.08	[−.05, .21]	−.43	[−.63, −.24]	.18	[−.04, .40]	.07	[−.09, .22]
Illustrated text (IT)	1.72	[1.59, 1.86]	−1.68	[−1.88, −1.48]	−.04	[−.27, .18]	1.52	[1.36, 1.67]
Film	.83	[.70, .96]	−1.24	[−1.43, −1.05]	−.26	[−.47, −.05]	1.01	[.86, 1.15]
Lecture	.68	[.55, .82]	−1.25	[−1.45, −1.05]	−.02	[−.24, .20]	1.25	[1.10, 1.40]
Reading	2.08	[1.95, 2.21]	−1.72	[−1.91, −1.52]	−.08	[−.30, .14]	2.35	[2.20, 2.50]
SART	.24	[.09, .39]	−.59	[−.81, −.36]	−.44	[−.69, −.19]	.08	[−.09, .25]
Scenes	1.37	[1.23, 1.52]	−1.59	[−1.80, −1.38]	−.02	[−.25, .22]	1.52	[1.36, 1.68]
Tobii EyeX	.02	[−.15, .20]	−.01	[−.12, .11]	.02	[−.12, .16]	.00	[−.10, .10]
Trial order	−.04	[−.05, −.03]	−.02	[−.04, −.00]	.02	[−.00, .04]	.02	[.00, .03]
Probe 2	.05	[−.00, .11]	−.04	[−.13, .04]	−.12	[−.22, −.03]	−.03	[−.09, .03]
Probe 3	−.01	[−.07, .05]	−.09	[−.17, −.01]	−.08	[−.18, .01]	−.07	[−.14, −.01]
MW × IT	−.63	[−.81, −.46]	.63	[.37, .90]	−.09	[−.38, .21]	−.07	[−.28, .13]
MW × Film	−.13	[−.32, .07]	.38	[.10, .66]	−.150	[−.46, .16]	−.02	[−.24, .19]
MW × Lecture	−.15	[−.33, .03]	.39	[.12, .65]	−.20	[−.49, .10]	.08	[−.13, .28]
MW × Reading	−.36	[−.54, −.18]	.51	[.24, .78]	.03	[−.27, .33]	−.24	[−.45, −.04]
MW × SART	−.08	[−.27, .10]	.15	[−.12, .42]	.00	[−.30, .31]	.10	[−.11, .31]
MW × Scenes	−.33	[−.52, −.15]	.55	[.29, .82]	−.18	[−.47, .12]	−.11	[−.31, .10]
				Random effects				
σ^2		.36		.72		.89		.42
τ_{00}		.22$_{\text{Participant ID}}$		.07$_{\text{Participant ID}}$		.09$_{\text{Participant ID}}$		.05$_{\text{Participant ID}}$
ICC		.37$_{\text{Participant ID}}$		.08$_{\text{Participant ID}}$		.09$_{\text{Participant ID}}$		.11$_{\text{Participant ID}}$
Observations		2,754		2,497		2,476		2,475
Marginal R^2/Conditional R^2		.42/.64		.22/.29		.03/.12		.53/.58

Note. Variations in sample sizes are due to missing eye tracking data. SART = sustained attention to response task; ICC = intraclass correlation coefficient.

(*Appendices continue*)

Table D2

Test Statistics for Variables in the Regression Models Assessing Gaze Control (25-s Time Window Before the Probe)

	Number of fixations		Fixation duration		Fixation dispersion		Saccade amplitude	
Predictor	χ^2(*df*)	*p*	χ^2(*df*)	*p*	χ^2(*df*)	*p*	χ^2(*df*)	*p*
Mind wandering (MW)	41.94 (1)	<.001	1.69 (1)	.193	5.19 (1)	.023	.78 (1)	.376
Task	2086.37 (6)	<.001	718.68 (6)	<.001	56.61 (6)	<.001	2984.21 (6)	<.001
Eye tracking setup	.07 (1)	.790	.01 (1)	.934	.08 (1)	.782	.01 (1)	.940
Task order	53.16 (1)	<.001	4.74 (1)	.029	3.11 (1)	.078	5.37 (1)	.021
Probe number	5.90 (2)	.052	4.61 (2)	.100	7.37 (2)	.025	4.91 (2)	.086
MW × Task	68.45 (6)	<.001	33.55 (6)	<.001	4.78 (6)	.573	15.44 (6)	.017

Note. *df* = degrees of freedom.

Appendix E

Minimum Detectable Effect Size by Task and Gaze Feature

Table E1

Minimum Detectable Effect Size (MDES) by Task and Gaze Feature for Mixed Effects Linear Regression Models

Task	Number of fixations	Fixation durations	Fixation dispersion	Saccade amplitude
SART	.30	.15	.35	.20
Audiobook	.45	.15	.40	.30
Reading	.05	.25	.30	.20
Illustrated texts	.15	.30	.35	.30
Scenes	.10	.25	.30	.25
Lecture	.20	.15	.35	.30
Film	.20	.20	.30	.25

Note. SART = sustained attention to response task.

Received April 2, 2019
Revision received February 28, 2020
Accepted February 28, 2020 ■