Blink durations reflect mind wandering during reading

Stephanie Huette (shuette@memphis.edu), Ariel Mathis, & Art Graesser
University of Memphis
Department of Psychology and the Institute for Intelligent Systems
369 Psychology Bldg
Memphis, TN 38152 USA

Abstract

Mind wandering is a prevalent but highly subjective phenomenon that is difficult to measure. Typically studies use probes at random points throughout at study that pop in and ask participants "Are you mind wandering" where they indicate yes or no, and then resume the study. This study investigated a method of extracting eye blinks from raw eye tracking data while participants were reading texts that varied in degree of engagingness on a similar topic. Blink durations were found to increase for less engaging texts. We hypothesize that eye blink durations may increase with mind wandering and discuss implications for mind wandering research.

Keywords: mind wandering, reading, eye tracking, consciousness

Introduction

Mind wandering is considered a state of moving from one thought to another internally, uncoupled from external stimuli (Smallwood & Schooler, 2006). There are task related thoughts (e.g. thinking about one's own experiences with making pasta while in a cooking class) and task unrelated thoughts (e.g. thinking about what to eat this evening while in a physics lecture). This is classically a difficult phenomenon to study, because we cannot directly observe the process of mind wandering unfolding, nor understand the contents of another's mind without directly asking about them. The process of asking participants to reflect on their mind wandering disrupts the process itself, interrupting the mind wandering and perhaps perturbing subsequent processing (Smallwood & Schooler, 2006). The focus of the present research is identifying a potential covert measurement of mind wandering that might globally index how engaged or disengaged a participant is with a given task.

Without focus on external stimuli we cannot process or learn new material from reading or listening nor can we do goal-oriented interactive tasks, all of which require attention, perceptual cognitive processing, and in some cases, action. This makes mind wandering important to understanding data from all domains of psychological research, because participants coming into a laboratory for many psychological experiment are likely to mind wander at some point during the task. However, mind wandering is not purely negative in its effects. More recently it has shown to play a role in aiding creative problem solving as well as autobiographical planning (see Mooneyham & Schooler, 2013 for a review). From a biological perspective it actually serves a functional role of resting the mind, even though it involves some of the same brain areas that are involved in tasks that require attention and goal-orienting.

Default Mode Network

The default mode network is hypothesized to be a network used when the mind is in a "resting state", supported by imaging research examining cortical regions involved in mind wandering (Mason, Norton, Horn, Wegner, Grafton & Macrae, 2007). Importantly the default mode network has been shown to be active during mind wandering using fMRI measurements, demonstrating a strong link between the phenomena of mind wandering and an underlying neural state (Christoff, Gordon, Smallwood, Smith & Schooler, 2009). This is a kind of auto-pilot the brain can use when it is not closely coupled to a stimulus, allowing the mind to process information internally. Allowing for a brief period of rest may allow subsequent performance on attention and focus-driven tasks to improve performance. The default mode network is active during many phenomena including mind wandering, daydreaming, thinking about the self, or thinking about the past or planning for the future (Spreng & Grady, 2010; Qin & Northoff, 2011). While the significance and meaning of the default mode network is a matter of debate (see Raichle, 2015), the literature provides hints into more covert measures of mind wandering that may be useful in detecting when a person becomes disengaged from a task. In the present work, we will demonstrate eye blink durations could be an indication the mind is wandering more often when reading difficult texts.

One recent study demonstrated eye blinks activating the default mode network temporarily (Nakano, Kato, Morito, Itoi & Kitazawa, 2013). Critically, this is not due to a temporary lack of stimulus from the eye closing. A condition where the video turned black for the duration of an eye blink did not produce the same pattern of activation as eye blinks. Thus, it can be inferred that blinks are linked to triggering the mind's resting state. When there is a task that involves close attention such as reading, the rate of blinking tends to decrease. Blinking is an underutilized resource for measuring engagement in a task. Part of this paper is to provide guidelines for extracting blinks from a continuous time series of eye movements.

Reading & Mind Wandering

Studies investigating text difficulty and mind wandering have been mixed. Self-report measures from people reading passages varying in difficulty demonstrated no differences in amount of mind wandering. Instead, differences in mind wandering were found in how interested the participant was in the topic (Giambra & Grodsky, 1989; Grodsky & Giambra,

1990). In more recent research, when text difficulty was varied (Feng, D'Mello, & Graesser, 2013), Difficult texts positively correlated with more self-reported mind-wandering. This is inconsistent with prior work that predicts simpler tasks to induce mind wandering (Smallwood & Schooler, 2006), presumably because there are more cognitive resources available for mind wandering. However, both overly easy and overly difficult tasks could both induce this kind of mind wandering. For the purposes of the present preliminary work, we are assuming there to be a correlation between mind wandering and how engaging a text is to read, in line with the Feng et al. findings (2013) where more mind wandering was correlated with more difficult to read texts. The second important link to the present work is between blinks and mind-wandering, which appears to be well-established.

Finding an observable behavioral characteristic of mind-wandering is a challenge. People are able to read entire pages of text while moving their eyes across the page while thinking about what they want to eat for dinner, making it difficult to predict or observe mind wandering without directly asking someone. Blinks have been investigated as an indicator of mind wandering. Smilek, Carriere, & Cheyne (2010) reported that blink frequency (blinks/sec) increased in periods prior to self-reported mind wandering during reading. However, this difference relied on separating the data according to self-report, whereas text difficulty was not varied.

Schad, Nuthmann, and Engbert (2012) proposed an attentional decoupling, finding that eye movements were predictive of overlooking text errors at different levels of language processing. The first level to be lost was the semantic/thematic information from text, followed by syntactic and lexical information, indicating mind wandering is not an on/off state of mind. This makes levels of language lost and degrees of mind wandering an important topic to pursue to understand what most impacts text comprehension and later recall (see also Uzzaman & Joordens, 2011). Other studies have also found that mind wandering is not a discrete state rather a gradual decoupling from external stimuli (Singh & Fawcett, 2008).

Study Motivation

Because prior research strongly points to the duration of blinks being linked to the default mode network, we hypothesized blink duration may also vary as a function of how engaging a text passage is during reading. This account is compatible with both the executive-resource hypothesis (Smallwood & Schooler, 2006) and a control-failure hypothesis (McVay & Kane, 2010), which both posit cognitive capabilities as important aspects to when and how mind wandering occurs. The present research asks if we can detect, using a covert measurement technique without probes, whether someone is mind wandering, and to what degree they are mind wandering? There is little research focusing on the temporal dynamics of how the mind transitions from a state of tight attentional coupling to the external stimulus to the internal train of thought that is detached from the external stimulus. This is phenomenologically one of the most interesting aspects of the experience of mind wandering, where in one moment you are listening to a lecture, and the next you realize you've missed the last ten minutes while thinking internally about the day's events, or future plans for the evening. Being able to detect when someone is about to begin mind wanderingis becoming of interest to more researchers and has been steadily progressing in recent years (Blanchard, Bixler, Joyce, & D'Mello, 2014; Bixler & D'Mello, 2014).

The goal of the current research was twofold: (1) to observe whether stimuli known to be less *engaging to different degrees* would produce blink duration differences, and (2) to observe this without the use of explicit probes. One of the challenges of mind wandering research is participants must be asked "Were you mind wandering?" at random points during experiments. While this approach typically yields interpretable results it poses problems that are readily acknowledged in the literature (Smallwood & Schooler, 2015). The first is it interrupts processing, perhaps perturbing subsequent mind wandering by bringing awareness and focus to the mind wandering aspect of the study. The second is participants may be engaging in mind wandering outside of their own awareness, or disengage to various degrees as a function of how engaging the current stimuli are. Asking if participants are mind wandering also does not reveal how deeply they are mind wandering. The blink frequency study of Smilek et al. (2009) used self-report, whereas we instead are relying on text characteristics to induce more or less mind-wandering. That is, mind wandering is predicted to decrease as a function of text difficulty, as we have shown in previous studies for these texts. We don't know whether or not participants in this particular study were indeed mind wandering but we rely on the established relation with text difficulty in this sample. Again, relying on self-report and probes also has its downsides in that it disrupts processing. Here we can rely on the assumption that more boring texts will induce more mind wandering (Feng et al., 2013).

Thus, instead of using a binary measurement of yes/no, eye blink duration affords a continuous measurement that could be sensitive to a spectrum of boring to engaging stimuli of all kinds. It also addresses the problem of interrupting processing because no overt response or knowledge of the study being related to mind wandering is required in order to collect eye movement data. This study may also help to address whether mind wandering occurs more frequently with engaging texts or with boring texts, helping to resolve conflicting results in prior studies.

This study includes one experiment and a description of methods on how eye blinks were extracted from a Tobii X2 system post-hoc. Eye trackers do not directly report whether samples are lost because of blinks, inaccuracy in calibration, head turns, or off-screen fixations. This poses a difficult computational problem for extracting blinks, and this algorithm could be used with any binocular eye tracking system. To determine a blink with high confidence, we used

only timepoints where both eye tracks were lost. We also used a reasonable duration of consecutive missing samples, because although eye blink duration has individual variability it is a relatively stable range. Single eye track loss is likely due to track loss from calibration error, and both eye samples being missing is likely to be looks off-screen. .

Educational outcomes are fundamentally tied to text comprehension and thus mind-wandering during reading is the focus of the present work. Three texts were given to all participants in randomized order, with similar thematic content and varying in degree of engagingness. We hypothesized blink durations would increase on the texts that were less engaging, regardless of the order in which they are read (which controls for fatigue effects). If the default mode network is activated with blinks, and less engaging texts induce more mind wandering, the duration of blinks will increase with less engaging texts, and decrease monotonically as text becomes more engaging.

Method

Participants

Thirty-nine undergraduate student participated in exchange for course credit in an undergraduate psychology course. Participants were right handed native English speakers with corrected to normal or normal vision by self-reported criteria. The study was not advertised as a mind wandering study to prevent self-selection.

Eleven participants were excluded from analysis due to low track quality, and one participant was excluded due to not finishing the experiment. Twenty-seven participants were included in the final analysis.

Design

The independent variable was text engagingness (3 levels). The data collected was a continuous stream of x,y pixel coordinates, sample presence or absence as indicated by the Tobii X2 system, as well as other standard data output from an eye tracker. The dependent measure to be derived was the average blink duration (in ms) per participant per condition. Other tasks were done after the reading, but this does not interfere with the results of the reading portion which is the only task to be discussed here.

Materials. The experiment was built using Tobii Studio and a Tobii X2-60 eye tracker was used to track eye movements. The experiment consisted of two segments: a blank screen and selected readings. Order of task type was kept constant, however the three levels within the reading task type were counterbalanced. The blank screen consisted of a dark gray screen which was used to gauge gaze behaviors in the absence of outside stimuli.

Three readings were selected to represent varying levels of engagement: high, medium, and low. Readings were historical in nature with topics including a selection of the United States Constitution, a reading on law and punishment in Plymouth colony, and an article on the Salem witch trials. Readings were presented one page at a time and were between seven and eight pages long.

Fixation points consisting of a white screen with a black and white target at the center were presented between tasks. Participants advanced past these by pressing the space bar on the keyboard.

Procedure. Participants were seated in a stationary chair at a Tobii X2-60 eye tracker. The research assistant briefly outlined the experiment and informed participants to use the space bar to advance after written instructions, fixation points, and through the readings. Participants were further instructed to hold their heads steady during the experiment and to not stare off screen. The eye tracker was then calibrated and the experiment was started. Written instructions indicating where the space bar should be used as well as the presence of the blank screen as the first task were shown on screen. Participants then stared at a blank screen for three minutes before the experiment automatically advanced.

The participants were next instructed to read through three selections and to press space bar to advance to each page. Readings were counterbalanced to control for order effects. Participants were not able to backtrack through the readings once they had advanced to the next page.

Data Processing. Both eyes were used and matched at each timepoint to see if one or both samples were present or missing. Timepoints where both eye tracks were lost, or one or both were present were calculated. If both eye samples were missing, these time points were counted as ones, and present samples were counted as zeros. The position of the eye is not relevant to the current analysis and so what remained was a vector indicating track loss for both eyes, continuously over the course of reading, linked with vectors of participant information and the text being read. Only samples where the participant was reading were used (e.g. instructions and calibration/drift correction screens were not used). The data was filtered so that only samples with both eyes missing for between 100 and 1000ms were counted. Prior research has demonstrated blink durations exhibit many individual differences but are within this range (Martens, Munneke, Smid & Johnson, 2006). For this reason a large range was chosen that is most likely to be a blink, and not sample loss due to track inaccuracies, head turns, or eyes closing deliberately for a longer duration.

Results. The text conditions were Low engagement, Medium engagement, and High engagement. Blink durations were an average of 320ms for Low engagement (StDev: 185ms), 258ms for Medium engagement (StDev: 94ms) and 224ms for High engagement (StDev: 51ms). A repeated measures ANOVA found a significant effect of text engagement level ($F(2,50)=4.6$, $p=.01$). This was in the direction of the more engaging the text, the shorter the blink durations. The results appear to be fairly consistent across participants, as seen in Figure 1.

Discussion

This study tracked eye movements over the course of reading three similar texts that varied in how engaging they were. We developed an algorithm to extract blinks from raw data, and found a relationship between blink duration and text engagingness, where longer blink durations were observed in less engaging texts. We hypothesize this reflects Default Mode Network activation, the brain areas and connections thought to be responsible for mind wandering.

However, this is very preliminary research that could have multiple interpretations. If blinks functionally trigger mind wandering as was observed in Nakano et al.'s work (2013), it could be that an increase in blinks slowly begin moving the mind deeper into the mind wandering state in a continuous fashion. That is to say, the reader may not be blinking because they are mind wandering, but instead, are mind wandering because they are blinking. While the current work cannot disentangle the directionality of what may be causing what, it is not impossible that blinks may be what allow the mind to wander more, and that the brain can anticipate this short rest period before the blink has even occurred (perhaps during the motor planning phase, Default Mode Network areas begin to activate). These are intriguing possibilities, and ones that might be addressed in follow-up research by incorporating imaging and EEG in conjunction with eye tracking.

Limitations

There are many limitations to the current work we readily acknowledge. The first is that we don't know if a given participant was mind wandering. It could be that some individuals did not mind wander and were very engaged in all the readings, while others were mind wandering for each passage. Follow-up research that includes probes or debriefing questions to measure mind wandering are necessary, and at this point we are assuming blink durations reflect mind wandering, when it could in fact be task difficulty, syntactic or lexical processing differences, or even something like word concreteness.

Other studies have quantified text characteristics using a tool called Coh-Metrix (Graesser, McNamara, Louwerse & Cai, 2004). This could potentially be used to control for text characteristics and various measures of text cohesion that

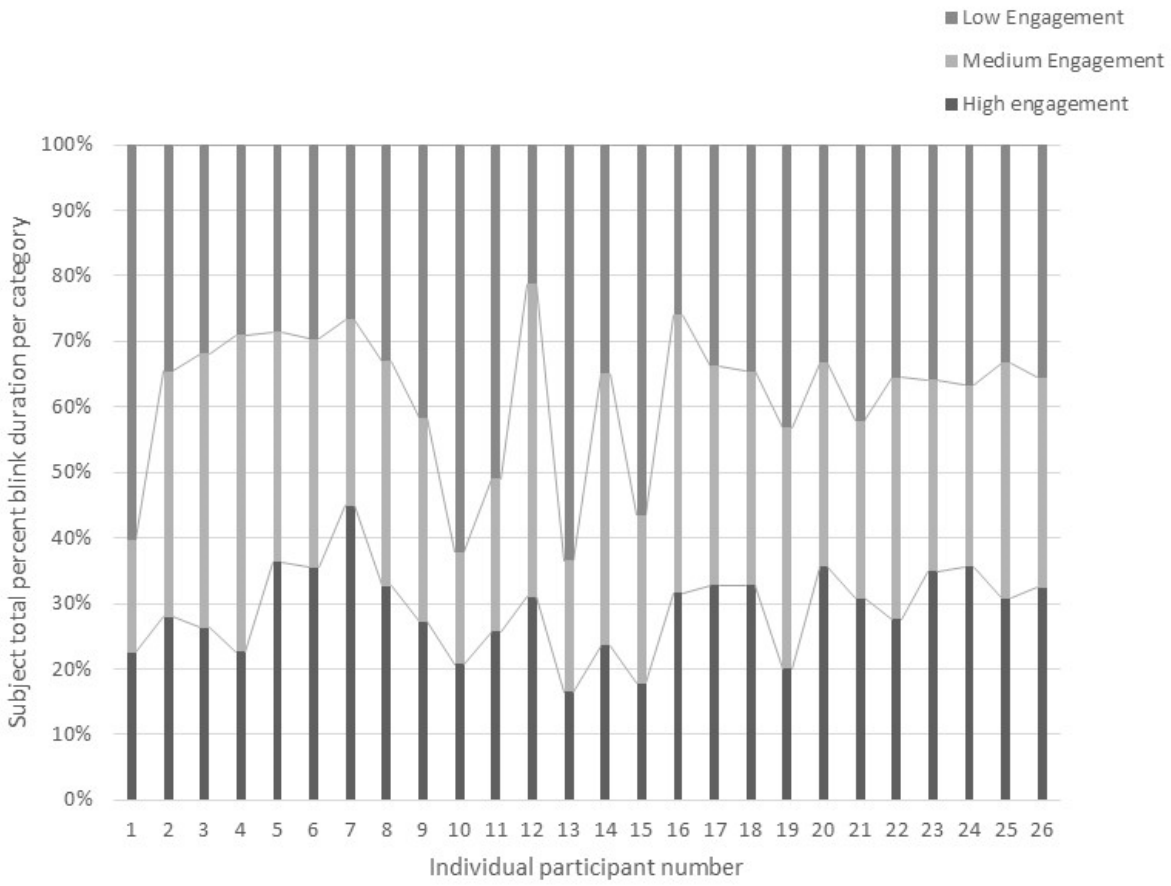

Figure 1 *Individual subjects blink duration by condition, as a total of all conditions.* Percentages are based on the individual's total average blink durations per condition. This shows the consistency of the effect, where it appears that most people show shorter blink durations for high engagement text, with few exceptions.

account for thematic language processing as well as other variables. It could be these characteristics that prompt one's mind to begin wandering, but this should be tested systematically.

The connection here between mind wandering and blink duration is tenuous but the data warrants further investigation. The literature and evidence showing a systematic difference between texts in this way does point toward this being an effect of mind wandering, but like all psychological measures, we have indirect evidence and more replication and validation of this paradigm will be required to establish this as an informative measure of engagement and mind wandering. We consider this first study to be observational rather than predictive, meaning

Conclusion

Despite many limitations, we have observed a connection between text engagingness and blink durations, meaning this is potentially a very useful measurement for future research in reading and mind wandering, and has the potential to quantify individual differences or may even be predictive of mind wandering starting to occur. With eye tracking technology becoming cheaper and more reliable, this could be used in conjunction with intelligent tutoring systems to help bring student's engagement back to the material. This could be generalizable to other stimuli and tasks as well, or even experiments without a task (such as passive listening to a story i.e. Huette, Winter, Matlock, Ardell & Spivey, 2014). This is the current direction of this research to generalize this to other tasks varying in the degree of engagingness, to help corroborate the current findings of differences in reading.

Acknowledgements

This work was supported by NSF grant # 1108845 to Sidney D'Mello and Art Graesser. Thank you to Sidney D'Mello and Andrew Olney for their helpful comments on this work.

References

Bixler, R. & D'Mello, S. (2014).Toward fully automated person-independent detection of mind wandering. In V. Dimitrova, T. Kuflik, D. Chin, F. Ricci, P. Dolog, G. J. Houben (Eds.), *Proceedings of the 22nd International Conference on User Modeling, Adaptation, and Personalization* (pp. 37-48). Switzerland: Springer International Publishing.

Blanchard, N.,Bixler, R., Joyce, T., & D'Mello, S. (2014). Automated physiological-based detection of mind wandering during learning. In *Intelligent Tutoring Systems* (pp.55-60). Springer International Publishing.

Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences, 106(21),* 8719-8724.

Feng, S., D'Mello, S. K., & Graesser, A. (2013). Mind wandering while reading easy and difficult texts. *Psychonomic Bulletin & Review, 20*(1), 586-592.

Giambra, L. M. & Grodsky, A. (1989). Task-unrelated images and thoughts while reading. In *Imagery*. (pp. 26-31). Springer US.

Graesser, A. C., McNamara, D. S., Louwerse, M. M., & Cai, Z. (2004). Coh-Metrix: Analysis of text on cohesion and language. *Behavior research methods, instruments, & computers, 36*(2), 193-202.

Grodsky, A. & Giambra, L. M. (1990). The consistency across vigilance and reading tasks of individual differences in the occurrence of task-unrelated and task-related images and thoughts. *Imagination, Cognition and Personality, 10*(1), 39-52.

Huette, S., Winter, B., Matlock, T., Ardell, D. H., & Spivey, M. (2014). Eye movements during listening reveal spontaneous grammatical processing. *Frontiers in psychology*.

Martens, S., Munneke, J., Smid, H., & Johnson, A. (2006). Quick minds don't blink: Electrophysiological correlates of individual differences in attentional selection. *Journal of Cognitive Neuroscience, 18*(9), 1423-1438.

Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae, C. N. (2007). Response to Comment on" Wandering Minds: The Default Network and Stimulus-Independent Thought". *Science, 317(5834)*, 43-43.

McVay, J. C., & Kane, M. J. (2010). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schooler (2006) and Watkins (2008). *Psychological Bulletin, 136(2),* 188-197.

Mooneyham, B. W., & Schooler, J. W. (2013). The costs and benefits of mind-wandering: A review. *Canadian Journal of Experimental Psychology/ Revue canadienne de psychologie expérimentale, 67*(1), 11-18.

Nakano, T., Kato, M., Morito, Y., Itoi, S., & Kitazawa, S. (2013). Blink-related momentary activation of the default mode network while viewing videos. Proceedings of the National Academy of Sciences, *110(2),* 702-706.

Qin, P., & Nordhoff, G. (2011). How is our self related to midline regions and the default-mode network?. *Neuroimage, 57*(3), 1221-1233.

Raichle, M. E. (2015). The brain's default mode network. *Annual review of neuroscience, 38*, 433-447.

Schad, D. J., Nuthmann, A., & Engbert, R. (2012). Your mind wanders weakly, your mind wanders deeply: objective measures reveal mindless reading at different levels. *Cognition, 125*(2), 179-194.

Singh, K. D., & Fawcett, I. P. (2008). Transient and linearly graded deactivation of the human default-mode network by a visual detection task. *Neuroimage, 41*(1), 100-112.

Smallwood, J., & Schooler, J. W. (2015). The science of mind wandering: Empirically navigation the stream of

consciousness. *Annual review of psychology, 66*, 946-948.

Smilek, D., Carriere, J. S., & Cheyne, J. A. (2010). Out of mind, out of sight eye blinking as indicator and embodiment of mind wandering. *Psychological Science, 21(6)*, 786-789.

Spreng, R. N., & Grady, C. L. (2010). Patterns of brain activity supporting autobiographical memory, prospection, and theory of mind, and their relationship to the default mode network. *Journal of cognitive neuroscience, 22*(6), 1112-1123.

Uzzaman, S., & Joordens, S. (2011). The eyes know what you are thinking: Eye movements as an objective measure of mind wandering. *Consciousness and cognition, 20*(4), 1882-1886.