Digital Distractions in Reading: Investigating Impact of Cognitive Control Training on Reading Behavior and Outcomes

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ABSTRACT

Characterizing the effects of notifications and pop-ups on reading comprehension, eye movements, and reader experience can deepen our understanding of digital reading behaviors. However, notifications are highly disruptive and can significantly impact reading performance: a challenge not easily mitigated even in controlled lab studies. We experimented (N = 22) to assess the impact of distractions like notifications/pop-ups on reading comprehension, frustration levels, and readability across 10 documents with varied distractions. The collected data include eye-tracking metrics and survey responses. We observed significant disruptions to reading flow, reduced comprehension, and increased frustration among participants with distractions. Furthermore, we examined the impact of cognitive control training on distraction management and comprehension levels, revealing improved comprehension in digital reading environments with distractions. Our findings provide quantitative evidence of the need for notification/pop-up management strategies that minimize disruptions and promote optimal reading experiences, with implications for the design of digital reading interfaces.

CCS CONCEPTS

• **Human-centered computing** → **HCI theory, concepts and models**; **Interaction paradigms**; • **Applied computing** → *Learning management systems.*

KEYWORDS

Eye-tracking, Distraction, Comprehension, Cognitive control

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1 INTRODUCTION

A significant hurdle to prolonged focused attention and reading comprehension is the pervasive presence of digital notifications in our daily encounters with technology. Given the increasing integration of digital gadgets into learning environments, it is imperative to comprehend the effects of these interruptions on the reading comprehension of participants. Previous research has explored the detection of interest and engagement in digital reading settings, laying the groundwork for this study [9, 14, 15].

Several studies have indicated that notifications can substantially interfere with the work at hand, causing concentration problems and decreased output [3, 7, 11, 17]. Notification frequency, placement, and content type are important variables that affect their impact on reading behavior and outcomes. Reminders and advertising are only a couple of the many notifications that may cause varying degrees of distraction. Reminder notifications, for example, may elicit quick acknowledgments, whereas ads may hold viewers' attention for longer [4]. Studies reveal that a simple notification does not interfere with reading; however, one that presents an important reminder will [5]. One important distinction to make is whether the notifications are connected to the current task, particularly in terms of how they affect reading comprehension.

Research by Peltz et al. (2017) has shown that distractions can prolong reading sessions and decrease comprehension [10]. Vadiraja et al. (2021) investigated the impact of distractions on attention by designing an experiment where participants were asked to count seconds while reading [19]. However, previous studies were limited by only using generic social media notifications from Facebook, Instagram, and Twitter. Our current study builds upon these findings by exploring a wider range of distraction categories and notification types, including alerts, news, ads, and reminders, displayed at various times and intervals, to provide a more comprehensive understanding of the effects of distractions on reading behavior.

Recent studies have explored the impact of digital distractions on reading performance, highlighting the adverse effects of frequent interruptions on comprehension and memory retention [2, 12]. These interruptions, often in the form of notifications, can significantly disrupt the flow of reading and necessitate a switch in attentional focus, thereby affecting overall task performance [6, 13]. Despite

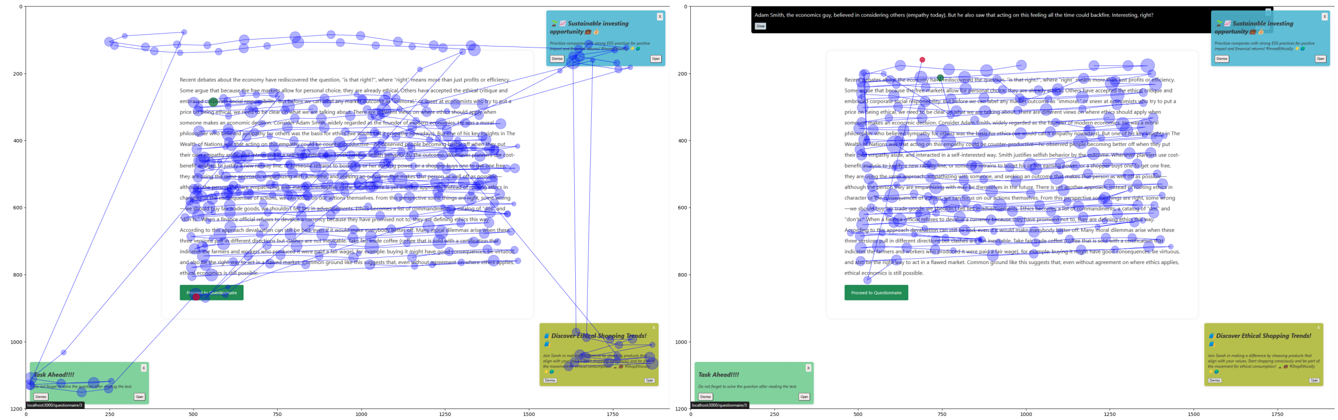

Figure 1: Scanpaths of gaze data for a highly distracted participant (left) who did not receive cognitive control training vs. a less distracted participant (right) who received cognitive control training on the same document.

these findings, there is a lack of research specifically examining the efficacy of cognitive control training in mitigating the negative effects of such interruptions. The main motivation behind this study is to investigate individuals' task-switching behavior when transitioning between reading and responding to notifications, with a focus on the role of cognitive control in this process. Building on previous research that shows individuals with higher cognitive control exhibit better reading comprehension and task-switching abilities [1, 8, 18], we investigate whether a brief cognitive control training session can improve reading outcomes in a distracted environment. To achieve this, we conducted a comparative study between two groups of participants. One group, designated as the control group, did not receive any cognitive control training. The other group, designated as the experimental group, received a 15-minute cognitive control training session before reading texts with varied notification types. This approach enables us to explore whether cognitive control training enhances reading comprehension and improves focus in a distracted environment.

The main goal of this research is to gain an understanding of natural reading behavior under the influence of distractions and the reading experience itself. We also aim to seek if training in cognitive control affects an individual's eye-tracking data-measured sensitivity to distraction and comprehension. The main contributions of this work are:

- An eye-tracking dataset featuring 22 participants reading 10 documents with varied distractions and pop-ups, providing valuable insights into reading behavior.
- A thorough examination and analysis using deep learning models to investigate how various types of distractions impact readers' comprehension, frustration levels, and document readability, as well as explore the correlations between these variables.
- An exploration of how cognitive control training influences readers' behavior and comprehension levels when faced with distractions while reading, offering potential strategies for improving reading outcomes.

2 METHODOLOGY

The system we implemented comprised eye gaze recording during reading sessions to assess readers' comprehension, distraction, frustration, and overall document readability. To accomplish this, we utilized a Tobii Pro remote eye-tracker, capturing gaze coordinates and pupil diameters at a robust sampling rate of 90 Hz.

2.1 Data Preprocessing

The raw gaze data from the eye-tracker collected was pre-processed to detect the fixations and saccades to plot the document scanpath. The raw x and y coordinates of gaze along with the left and right pupil diameters were primarily used to predict distraction, comprehension, and frustration levels. Figure 1 shows a comparison of gaze data from two participants reading the same document, with one participant having received cognitive control training and the other not having received training. A sliding window of length ten seconds with 50% overlap of data was used for the analysis.

2.2 Models

In our study, three different neural network models were employed to analyze and detect the participant's distraction, comprehension, and frustration. The recorded gaze data was analyzed using a CNN-LSTM, InceptionTime, and Transformer model. The CNN-LSTM extracted spatial and temporal features from gaze data to classify reading patterns, InceptionTime used an ensemble of multiple inception blocks where each inception block consists of convolutional layers, and Transformer identified dependencies and relationships using self-attention mechanisms.

2.3 Classification

The neural networks were trained to predict three key outcomes: distraction, comprehension, and frustration: based on participants' self-reported experiences. Participants rated their experiences on a scale of 1 (very low) to 5 (very high) for each outcome. These ratings were then categorized into binary classes: Low (ratings 1-3) and High (ratings 4-5), enabling a binary classification approach.

Table 1: Comparison of Models with LOPO and LODO validation methods

Models	Validation Method	Distraction		Comprehension		Frustration	
		Accuracy	F1 Score	Accuracy	F1 Score	Accuracy	F1 Score
CNN-LSTM	LOPO	0.72	0.67	0.75	0.67	0.79	0.70
	LODO	0.79	0.71	0.80	0.72	0.81	0.74
InceptionTime	LOPO	0.70	0.65	0.72	0.63	0.75	0.69
	LODO	0.73	0.68	0.77	0.69	0.79	0.71
Transformers	LOPO	0.74	0.68	0.76	0.66	0.79	0.72
	LODO	**0.80**	**0.73**	**0.83**	**0.75**	**0.85**	**0.77**

2.4 Evaluation Protocol

We employed two data partitioning techniques to split our data into training and testing sets: participant-independent and document-independent approaches. The participant-independent approach, also known as leave-one-participant-out (LOPO), involved designating one participant's data as the test set while using the remaining participants' data for model training. This process was repeated for each participant, and the average accuracy was calculated to evaluate overall model performance. Similarly, the document-independent approach, or leave-one-document-out (LODO), involves using one document for testing and the remaining documents for model training. This process was repeated for each document, and the average accuracy was calculated to evaluate overall model performance.

3 EXPERIMENTAL DESIGN

A total of 22 university students (14 female and 8 male, aged 23-32, M=26.48, SD=3.20) were recruited as participants for this study. All participants joined the experiment after providing informed consent, and they had the freedom to withdraw from the study at any point if they chose to do so. The detailed information about data consent, sensor usage, and the experiment sessions were communicated to all participants before their participation in the study. They were instructed to read ten texts, each approximately 500 words in length, covering general topics, ensuring no prior knowledge advantage. Eye movements while reading were recorded using a Tobii pro remote eye-tracker with a sampling frequency of 90 Hz. The participants read the documents on a desktop computer with the eye-tracker mounted on the screen in a controlled environment, ensuring that all participants had a consistent screen size and resolution. The study followed a mixed-method approach, with the effect of cognitive control training studied between the set of participants. For each participant, the texts were interrupted by notifications/pop-ups of random sales advertisements, emails, or reminders. All the notifications appeared either at the corner or the top margin of the display at different time intervals. Participants were not instructed on whether they should close the notification pop-up or not, to preserve their natural response.

To investigate the effect of cognitive control training (CTT) 11 out of 22 participants (experimental group) had to perform an adaptive version of the Paced Auditory Serial Addition test (PASAT) [16] after which they were presented with the texts to read. To ensure the participants were actively reading the texts, they also had to complete an objective comprehension questionnaire in addition to the subjective comprehension questionnaire. Moreover, document-wise subjective measures of participant's distraction, comprehension, frustration and overall readability were collected on a 5-point scale with 1 being the least and 5 the highest value.

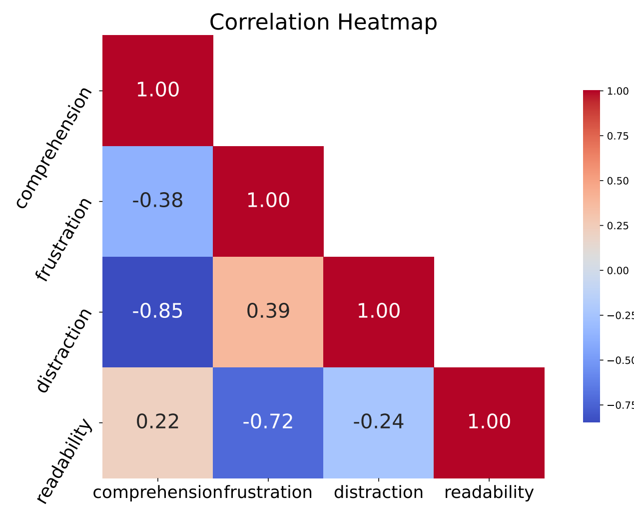

Figure 2: The correlation heatmap of the survey responses

4 RESULTS

This study employed binary classification using three deep neural networks to predict participant distraction, comprehension, and frustration levels. The model performance was evaluated using LOPO and LODO validation methods, with results presented in Table 1. Notably, all models achieved better predictive outcomes with the LODO approach, and the Transformer model exhibited slightly superior performance across all labels. Specifically, the Transformer model achieved an accuracy and F1-score of 0.80 and 0.73 for distraction, 0.83 and 0.75 for comprehension, and 0.85 and 0.77 for frustration, respectively.

The correlation plot in Figure 2 revealed significant relationships between the variables. A strong negative correlation was observed between comprehension and distraction (r = -0.85) as expected, indicating that as distraction increases, comprehension decreases, and vice versa. This suggests that more distracted individuals tend to have lower comprehension levels and lower readability. Furthermore, a moderate positive correlation was observed between

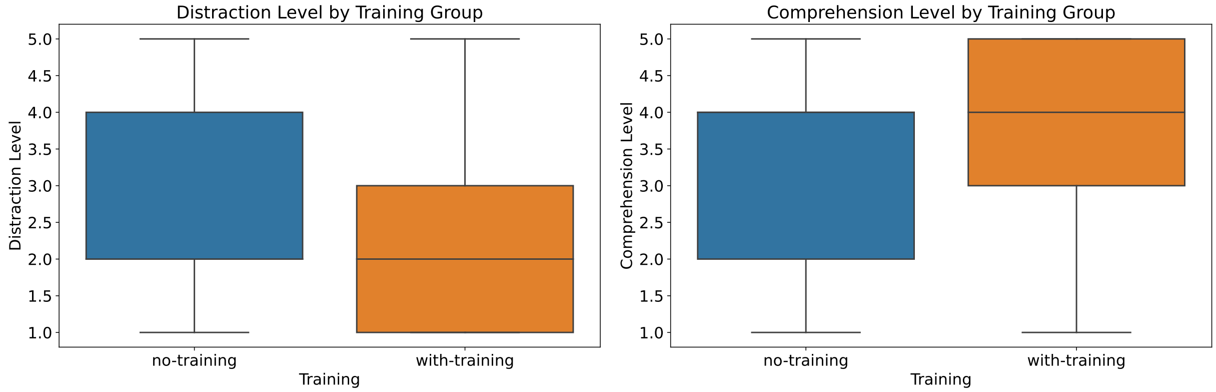

Figure 3: Comparison of ratings between participants with cognitive control training and those without.

frustration and distraction (r = 0.39), suggesting that as distraction increases, frustration also tends to increase. Interestingly, a weak positive correlation was found between comprehension and readability (r = 0.22), indicating that as comprehension increases, readability also tends to increase, but the relationship is not as strong as the other correlations. These findings have important implications for the design of learning materials and environments, highlighting the need to minimize distractions and frustration to promote better comprehension and readability.

5 DISCUSSION

The findings of this study demonstrate the effectiveness of deep neural networks in predicting cognitive and emotional states and have implications for the development of personalized learning systems. Distractions like pop-ups or notifications tend to hinder comprehension and document readability and are associated with higher frustration levels as observed from the study.

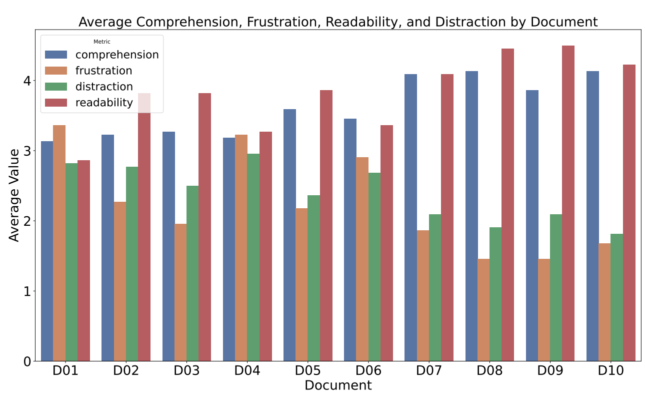

Figure 4: The average comprehension, frustration, readability, and distraction across each document as reported by the participants

To enhance comprehension in a distracting reading environment, we assigned 22 participants to either read documents without training (*P01-P11*) or receive cognitive control training (*P12-P22*). Our results indicate that the trained group exhibited improved comprehension and reduced distractions compared to the untrained group. To validate these findings, we analyzed both objective and subjective questionnaires. Figure 3 illustrates the comparison of ratings between the trained and untrained groups, revealing a significant increase in comprehension levels and a decrease in distraction levels among the trained participants, supporting our hypothesis. The training had a significant impact on improving comprehension (*p-value = 0.0059*) and reducing distraction levels (*p-value = 0.021*), but not on frustration levels (*p-value = 0.899*). Figure 4 depicts the average ratings provided by participants after reading each document, indicating that some documents with higher comprehension and readability are associated with less distraction and frustration.

However, there are several limitations and challenges to this study that should be acknowledged. The small sample size of 22 participants may not be representative of the larger population, and future studies should aim to recruit a more diverse and larger sample. The study's reliance on self-reported measures of comprehension, frustration, and readability may be subject to biases and limitations. Finally, the study's inability to control for extraneous variables and individual differences in cognitive abilities and reading habits may have impacted the results, highlighting the need for more rigorous experimental designs and control conditions in future studies.

6 CONCLUSION

This study demonstrates the disruptive impact of notifications and pop-ups on reading comprehension, frustration levels, and reader experience. A group of 22 university students were recruited to read ten different documents followed by a survey. The findings suggest that deep neural networks can effectively predict distraction, comprehension, and frustration levels. While cognitive control training can improve comprehension in digital reading environments with distractions, the findings highlight the need for effective notification and pop-up management strategies to minimize disruptions and promote optimal reading experiences. The study's results have important implications for the design of digital reading interfaces, emphasizing the importance of reducing distractions to enhance reading performance and overall reader experience.

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