An analysis of reading process based on real-time eye-tracking data with web-camera——Focus on English reading at higher education level

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Abstract

Reading skill, an important and complex cognitive ability, is one of the target skills for talent training. Especially with the trend of online learning becoming more and more prevalent, digital reading literacy is a necessary skill for learners. Therefore, many researchers started to focus on study reading process, and study methods are diverse, such as by collecting eye movement data. However, most researches were limited to scope of laboratory, so it is difficult to achieve low-cost, large-scale, non-invasive and objective reading process data collection and analysis. Therefore, this research developed a platform using web camera of laptop and open-source eye tracking library (webgazer.js) to get physiological indicators based on eye tracking data, which can be used to analyze reading process and explore the impact of the reading performance. This research also used inferential statistics and machine learning methods to quantitatively characterize and analyze the relationship between reading behavior and reading performance. This study's conclusions can help make subsequent targeted adjustments and interventions to improve learners' reading performance, and prove the usability for collecting eye-tracking data by platform with web-camera.

Keywords

Text reading, Eye tracking, Web-camera

1. Introduction

Reading skill is an important and complex cognitive ability, and is always regarded as one of the most significant skills for learning and living in future life. Especially with the prevalence of online learning, digital reading literacy is an indispensable skill for everyone to study online[1]. The PISA, which is internationally authoritative, has focused on the evaluation of reading literacy for a long time. Since 1997, reading literacy evaluation was prepared to be included in PISA by OECD(Organization for Economic Co-operation and Development). And then, reading skills were regarded as one of the most important abilities that future talents should have in the PISA 2000. In the relevant report of PISA 2018 reading training was regarded as an important way to improve reading literacy[2], and digital reading literacy was particularly highlighted[3]. However, most of current researches on reading skills were resultant in measurement and evaluation of reading skills, ignoring the interpretation and analysis of the reading process, that is, the internal mechanism and principle of the reading process is not yet clear[4]. Traditional research methods are difficult to get non-invasive and objective reading process data collection and analysis, which will influence the objectivity and reliability of the analysis results, such as self-report. Therefore, researches begun to analyze the reading process based on physiological indicators, such as eye tracking data, electroencephalogram (EEG), and so on[5].

As far as existing research is concerned, eye tracking has been widely used, and was regarded as an effective tool for analysis of reading process[6, 7]. It because that 80%-90% of human information is

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© 2022 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0). CEUR Workshop Proceedings (CEUR-WS.org) obtained through the human visual system in general[8], especially reading during the learning process[9]. Existing studies often use eye tracking data for the studies of cognitive processes such as reading[10]. The analysis , to a certain extent, can reflect participants' attention distribution and instantaneous cognitive processing during cognitive processing process[11], which can also be visually presented and characterized[9, 12, 13] for interventions and adjustments provide a data basis. However, eye tracking often needs expensive instruments, equipment and professional venues to support. For online learning, laptop screen mount devices can be carried out much easier for the collection and analysis of eye tracking data[11]. In order to achieve a more comprehensive analysis, research tools need to be developed.

In general, the contributions of this research are summarized as follows: (a) We build a platform for the reading process to realize eye tracking based on web-camera, and then explore the relationship between reading behavior indicators and reading performance based on statistical analysis methods and machine learning methods. The results obtained can explore the laws that exist between reading behavior and reading performance. (b) By conclusions obtained in this research with the conclusions of existing research, it can further prove the reliability of the eye tracking platform for the reading process constructed by this research. The platform can use for low-cost, large-scale, and convenient collection of eye tracking data during the reading process in subsequent research, and further explore the relationship between reading behavior and reading performance. The rest of the paper is structured as follows: Section 2 introduces background and related work. And then, Section 3 shows methodology and process of our experiment. Moreover, Section 4 presents our results. Finally, Section 5 concludes and proposes directions for future work.

2. Background and Related Work

2.1. Reading

Reading skill is an important ability for higher education learners, because it is an important influencing factor for future work and lifelong learning[14]. For example, the development of reading ability was emphasized in the European Commission, which can help individuals achieve personal development and integration with society[15]. For example, studies have shown a correlation between the level of development of reading skills and future socioeconomic status[16], that is, reading ability refers to a kind of ability that is very important for learning, work, social life, and so on. So, with the help of complex cognitive activities such as meta-cognition to understand text, and then it can realize the screening and details of information, related inferences, and problem solving[16]. Researchers in related fields, such as OECD, believe that reading can effectively help learners improve their reading skills[18]. Therefore, it is crucial to use learning analytic for help educational practitioners achieve targeted interventions and moderation.

2.2. Eye tracking

Eye tracking technology is currently widely used in the study of complex cognitive processes such as reading. It is mainly supported by eye-mind-assumption[19], and that is to say, gaze can represent what the brain is processing. Therefore, researchers regarded eye tracking data as indicators that can reflect the individual's timely cognitive processing[20]. With the aid of eye tracking technology, the reader can be quantified and visualized in the cognitive process. The focus, attention, and scanning patterns of the system are measured to reflect the timeliness of cognitive processing in the process[21]. So, eye tracking technology is more convenient and feasible for studying complex cognitive activities such as reading. The main reason is that eye tracking technology can be integrated into existing digital learning equipment to collect eye tracking data in natural situations in a non-intrusive way [21], such as a web camera based on a laptop, which can be used as a device to realize eye tracking. Compared with eye movement activity assessment glasses (also called mobile eye trackers), and eye trackers embedded within virtual reality headsets, laptop-based eye-tracking devices have slightly insufficient accuracy[13], but it can avoid the interference and high cost caused by new equipment. In addition, it is a relatively convenient solution for data collections of eye tracking in the digital learning process[11].

Additionally, the existing eye tracking data is often used in business, medical and other contexts[22], but there are no effective learning analysis related research results to support how to use these data to improve learning performance in the education field[22]. Therefore, we can develop one eye-tracking platform based on web-camera of laptop.

2.3. Analysis of reading based on eye tracking

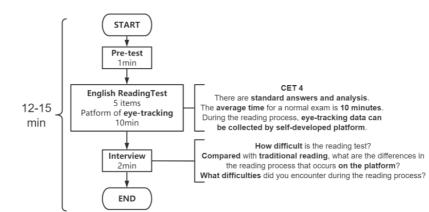
From the perspective of data, indicators of eye tracking data are meaningful for the analysis of complex cognitive activities such as reading. This can be supported by eye-mind hypothesis, which was present in former content. Based on this theory, we can know that if one person focuses on an area over certain time, they probably have difficult to understand the information, or was bored with information in this area. In existing researches, indicators can be divided into two categories, namely, visual representations such as heat maps, and quantitative representations such as annotation rates[21]. Based on these data, Area of Interest (AOI) can be identified during the individual cognitive activity. This means that the learner may have cognitive difficulties or higher interest in the corresponding area[24]. For example, in the process of designing and optimizing the learning platform, the relevant data of eye tracking can be used as auxiliary decision-making information[10]. Another common indicator, which can reflect the difficulty of understanding is regressions[11]. It reflects learners frequently review former information to help understanding all information, when they is processing difficult information. These data indicators have relatively mature calculation methods in related researches[8], and are widely used in reading-related research, such as the measurement of reading literacy ability[25, 26]. Related research shows that experts may behave in the reading process with the characteristics of shorter fixation duration, less fixation and retrospect[4].

Analyzing reading from the perspective of learning content can be approached from two different levels. First of all, vocabulary is an important influencing factor and predictive factor for text reading[4]. This is mainly because in the reading process not only a certain vocabulary is required, but the ability to integrate context, collocation, and grammar[29] for more comprehensive and accurate understanding is necessary as well. Secondly, focus on the global text, the learner's mastery and understanding of the full text are based on the analysis results of the learner's scan path and other data in the reading process. Among them, the subject's first fixation time, regressions and other related indicators can reflect the different reading strategies of learners[30]. This is a research perspective of reading analysis that has attracted more attention.

Therefore, the main research question of this study is whether the reading behavior reflected by the indicators collected by self-developed reading platform for eye-tracking in the reading process obtained by eye tracking will have a significant impact on the effect of reading? Based on above analysis, we formed two hypotheses: (a) H1: There is a significant correlation between some reading process behavior indicators and reading performance. (b) H2: Some indicators with specific meanings have a significant impact on academic performance`.

3. Method

This research designed and implemented an experiment to explore., and the details of the experimental process are shown in the figure 1. This research used eye tracking technology to obtain learners' reading behavior data during English reading tests. Participants speak English as a second foreign language. Finally, the subjects were interviewed, which means to know if there are some difficulties during the test and help verify our conclusion[6, 31]. The sample consisted of 35 higher education learners from a college in East China. They use English as a second foreign language and have basic English reading ability and logical reasoning ability. The effective sample size is 32. Before the experiment, we obtained the informed consent of the subjects. One English reading test of CET 4 were selected as the reading materials, and can see more in Figure2 and 3.



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Figure2: Example of video recording and system screen recording interface during the experiment

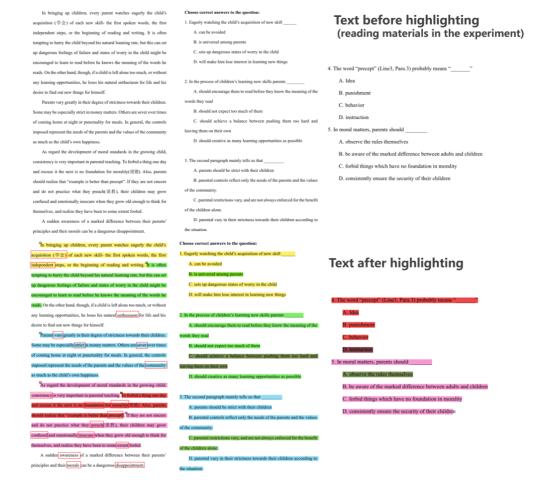


Figure3: Reading text before and after highlighting (the different color represent different items and coresponding text)

The experiment uses a laptop computer with a 46.67-cm (14 in.) diagonal display, a 720pHD camera (about 920,000 pixels), which used for eye-tracking devices during the experiment to realize non-intrusive data collection. And, an eye tracking library, webgazer.js (https://webgazer.cs. brown.edu/), can predict the user's eye-gaze location[32]. During reading process, the system can automatically get the positions of the pdf window on the screen, the current page number, and the distance between the top of the current page and the top of the current pdf window in real time. And then system can judge the eye-gaze position predicted by webgazer.js to fall within which line, and, that is to say, the content read by the user at the current moment can be predicted. Based on these, we develop a software called Readgazer. We used HTML5, Flask back-end framework and MongoDB database to develop such a system, and used python 3.9 and SPSS to analyze data. The average error with the best model in the experiment was at about 130 pixels. In order to combine the reader's eye-gaze position with the text content in the document, we use pdf.js (https://github.com/mozilla/ pdf.js/) to render pdf documents. So, we can get basis to compute eye-tracking indicators.

4. Results

The reading test selected in this study includes five questions in total (T1, T2, T3, T4 and T5). Since the types and difficulty of the questions are different, the correlation and influence of them will be explored respectively. For the acquired data, SPSS 21.0 is used for Inferential Statistical Analysis, and use algorithm in machine learning to do data mining, and further analyze the relationship between reading behavior and reading performance. Eye-tracking indicators are shown in table 1.

Table 1:

Eve-tracking	indicators	for reading process
	maicators	for reduing process

Indicators	Indicators Interpretation of indicators						
freq_i	Frequency of fixation on page i (The number of fixations on all rows on page i)						
pagefreq_on_rate_i	Fixation rate on page i (Number of fixations on page i/total number of fixations on all pages)	There are a total of 3					
freq_i_j	Frequency of fixation in line j on page i (The number of fixations on row j of page i)	content and					
freq_rate_i_j	Fixation rate in line j on page i (Gaze rate on line j on page i)	23 lines of text, and					
pagefreq_onpage_rate_i	Fixation rate on page i (Number of fixations on page i/total number of fixations on page i)						
pagefreq_onpage_rate_total	Fixation rate on all pages (Gaze rate on pdf, the number of fixations on the pdf / the number of fixations on the overall web interface.)						
page_forward_back	Frequency of regressions(RS) among pages. Such as looking back from page 2 to page 1. (The total frequency of page backwards)						

4.1. Analysis of reading based on eye tracking

Correlation and regression analysis results of eye-tracking indicators and reading performances are shown in Table2. In this study, the main of correlation analysis was to filter indicators, which has significant relation with score of each item. Then, logistic regression analysis can use these indicators to identify key indicators, which can have significant relationship with reading performance for each item. For reading performance of T2, there is no significant correlation with all reading behavior indicators, which means that no reading behavior indicator can significantly influence T2 reading performance.

Table 2:

Correlation between eye-tracking indicators and reading performance (there just present some indicators have significant relationship with reading performance)

	Correlation analysis			Logistic regression analysis											
Items	Indicators	Correlation coefficient	n	Hosmer & Lemeshow	Nagelkerke R ²	Percentage accuracy	ltems(Z) B	S.E	Wals	df	Sig.	Exp (B)	95% C.I. for EXP(B) Lower Uper		
T1	freq_1_3	0.362*	_0.016	5 0.308	0.222	59.40%	pagefreq_								
	pagefreq_onpag e_rate_1	0.359*					onpage_r ate_total	1.337	0.767	3.044	1	0.081	3.809	0.848	17.114
	pagefreq_onpag e_rate_total	0.372*					Constant	-0.47	0.449	1.094	1	0.296	0.625		
Т3	page_forward_b ack	-0.355*	0.020	0.335	0.206	62.50%	freq_1_19	-1.042	0.521	3.999	1	0.046	0.353	0.127	0.979
	freq_1_19	-0.378*					Constant -C	-0.187	70.388	0.231	1	0.631	0.83		
	freq_1_20	-0.376*													
	freq_2	-0.351*													
	freq_rate_1_12	0.379*	_	4 0.508	0.264	81.30%	freq_3_5 -1.089 0.								
	freq_rate_1_13	0.350*	0.014					-1 080	180 0 102	1 907	1	0 0 2 7	0 336	0 1 2 8	0 882
T4	freq_1_20	-0.380*						0.452	4.907	1 0.0	0.027	0.330	0.120	0.002	
	freq_1_21	-0.405*													
	freq_2_12	-0.380*					Constant 1.542		.542 0.522	8.709		1 0.003			
	freq_3_4	-0.388*						1.542			1		4.672		
	freq_3_5	-0.443*													
T5	freq_2_2	0.360*	0.002	0.733	0.432	71.90%	_2_8	5 0.519	4.464		1 0.035	2.992			
	freq_2_8	0.356*								1			1.083	8.267	
	freq_rate_2_8	0.369*													
	freq_3_1	0.400*	-				freq_3_2							1.147	16.215
	freq_3_2	0.405*					Constant	0.367	0.448	0.669	1	0.413	1.443		

Take T1 as an example to explain the data analysis results in Table2. From table 2, we can find that there are three indicators significantly correlated with the performance of learners on the first question. Based on this, results of logistic regression using the selected indicators indicate that "pagefreq onpage rate total" can predict the learner's correct rate on the first question. Although, p value less than 0.05, and "Hosmer & Lemeshow" value more than 0.05, which means that the logistic analysis result of T1 with responding indicators is statistically significant. Nagelkerke R2 is 0.222, which shows that this logistic regression model can explain 22.2% of change in dependent variable. Percentage accuracy represents that 59.4% results of predict are correct. But, sig value of pagefreq_onpage_rate_total is 0.081 more than 0.05, which means that the prediction of this indicator is not statistically significant. Based on this, we can conclude that the higher the proportion of the participant's annotation frequency to the overall text, the more concentrated the participant's attention, and therefore the better the participant's answering performance on T1.It should be noted that in order to be able to compare the difference in importance between different indicators in the same logistic regression analysis result, the study standardized all indicators by Z-score before performing logistic regression analysis. For example, the logical analysis result of T5 shows that freq_rate_2_8 has a greater influence on T5's reading performance prediction than freq_3_2.

In general, through the correlation analysis and logistic regression analysis of each topic, we can find that: (a) For a relatively simple topic such as T1, as long as the participant can ensure concentration during the reading process There is a great possibility that the answer is correct. (b) For topics such as T3 and T4 that indicate the approximate area of the corresponding article content, the more participants pay attention to the corresponding content or topic of the reading article, it means that the participant has processed more information in that area. The processing process, that is, the subject may have doubts, so the subject's performance on the corresponding question will be worse. (c) For T5 topics that do not indicate the approximate area of the topic corresponding to the content of the article, the higher the participant's attention to the topic and the corresponding text content in the text, the more information is processed and processed at the corresponding location. There is no proof of a specific

text content area. After the correct content can be recognized, the subject will further confirm the text content and the topic. Therefore, the more subject focus on corresponding area, the more correct may be.

4.2. Machine learning analysis

In order to be able to more clearly characterize the predictive effect of behavior indicators on reading performance, the decision tree and random forest algorithm in machine learning is used in this study to further determine the impact of behavior indicators on the prediction of reading performance results under different circumstances.

When it comes to the data mining of machine learning, behavioral indicators in the reading process can make more accurate decisions for reading performance. The results are summarized in Figure 4, class 0/1 mean not correct/correct answers. Take a branch of T2's decision tree model as an example to explain in detail. Decision tree model of T2 is shown in the Figure 4, and a relatively high accuracy (acc=0.745) is obtained after three-fold cross-validation. As can be seen from the figure, if freq_rate_2_19 less than or equal with 0.004 and freq_rate_1_3 less than 99.0, it can judge that subject may get correct answer for T2. Further, if freq_rate_2_19 more than 0.004, and pagefreq_on_rate_2 less than or equal with 0.166, which means that answer for T2 has a great possibility that it is right correct. Therefore, from the decision tree, we can predict the possible answer of the subjects on the corresponding questions based on the indicators under different threshold conditions.

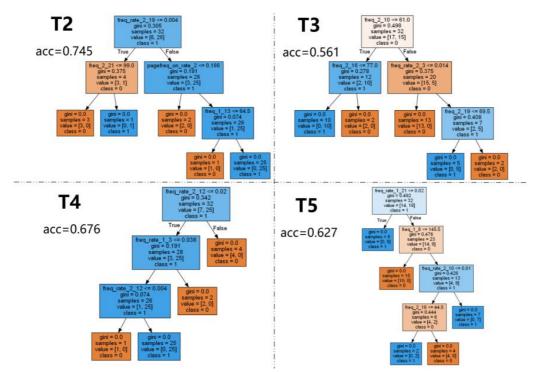


Figure 4: Decision tree models for each topic with acc value greater than 0.5

And then, in order to judge and identify the importance of indicators, random forest models were constructed in this study. The results are shown in the Figure 5. The importance of the index is calculated by using the Leave-One-Out Cross Validation method to construct the training set and the test set, and then obtain the importance of 32 random forest models and the corresponding indexes, and then take the average of the 32 importance, and use this as the basis Sort all the indicators and find the 10 most important indicators corresponding to the missing questions. Among them, the acc value representing the accuracy of the model is marked in Figure 5. From Figure 5, we can further get information as follows. Relatively speaking, the index of the title and the corresponding article content area is more important for prediction of reading performance. Take T4 for example, we can find that freq_rate_2_12 is the most important indicator for prediction of T4. Freq_rate_2_12 is the aera of T2,

which means that students fouce on T2 may influence the performance of T4. So, we can further study the reson why cause this result. From this result, we can further get information about the indicators' importance for each item.

Therefore, the more focus on text content related to topic, the more cognitive attention allocated on it, and that is to say, there may be confusions for participants; Relatively low fixation rate on the topic and text indicates that there is relatively little cognitive processing on the topic and there is no confusion. So, the behavioral data during reading can be used to predict the corresponding reading performance after learning analysis.

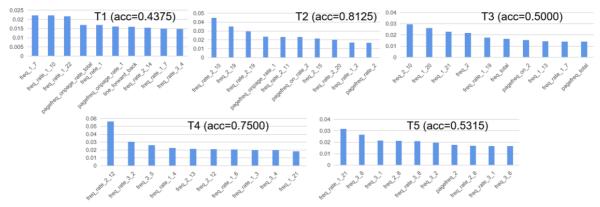


Figure 5: The top10 indicators of each random forest model for each item

5. Discussion and Conclusion

Based on the above analysis, we found that the more focus on content or topic, the worse reading performance would be, which is also supported by the existing studies. When it comes to the reason, the higher values of the indicators, such as freq_2_19, represent participants' cognitive processing of reading on the corresponding content, which means that there may be cognitive processing difficulties. Therefore, indicators with larger value associated with poorer reading performance. This is consistent with the conclusion of existing studies. For learners with weak reading skills, they will pay more attention on information processing, which can represent learners' efforts, and can also be indicators to reveal reading difficulties. Therefore, future studies can use our developed reading platform, which can collect eye-tracking data. And then, in order to improve reading performance, it needs to be considered that how to intervene and adjust from key eye-tracking indicators. The significance of this study is that the developed system can well capture the user's reading behavior data during reading process, which can be the basis of studying reading performance improvement, and quantify the influence relationship between behavior indicators and reading performance.

However, the study also has some shortcomings. Firstly, since the system is developed by research team members based on the open-source code and tools, the accuracy in operation is difficult to compare with the current mature system or eye-tracking tools. This system will be modified and improved in the future. In other words, the accuracy of this system need to be improve, which lead the results of this research to have a certain deviation, so we will improve the system. Secondly, due to limited human resources, the number of subjects is small, so there is less data. Therefore, it is difficult to conduct the high-precision machine learning data mining, and the precision of the decision tree and random forest models is poor. The sample size will be further increased in subsequent studies to get more valuable conclusions.

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