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A REVIEW OF RESEARCH ON THE RELATIONSHIPS BETWEEN READING FLUENCY AND EYE MOVEMENTS AMONG STUDENTS

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ABSTRACT--*This paper presents a systematic literature review of literature on eye-tracking and reading tasks by using 20 studies in total from abroad and local, which were published between 2015 and 2019. This paper aims at scrutinizing trends and gaps based on the observation from the literature regarding the usage of eye-tracking devices in examining the relation between eye movements and reading fluency. Six main findings emerged: (a) there is a fairly constant interest in trend for incorporating eye-tracking in measuring eye movements during reading; (b) inefficiency to generalize to real-word reading tasks; (c) there is a scant studies on population from diverse backgrounds; (d) the relation between eye movement patterns and underlying cognitive processes is scarcely reported; (e) there is a scarce of eye-tracking studies conducted locally. These findings were analyzed to determine the the implications on the research development of eye-tracking towards reading fluency.*

Keywords--*Eye-tracking, eye movements, reading fluency, reading task, cognitive processes.*

I. INTRODUCTION

An abundant of scope of studies on eye movements concerning reading fluency has been conducted widely since the early 1900s. Rayner (1998) stated that the first era revolved around "issues such as saccadic suppression (the fact that we do not perceive information during an eye movement), saccade latency (the time that it takes to initiate an eye movement), and the size of the perceptual span (the region of effective vision)" (p. 372). Subsequently, a study by Barnes, Kim, Tighe and Vorstius (2017) summarized that many researches pertaining to eye movement to measure reading fluency focused on the perceptual span, lexical level of reading, word skipping, regressions and fixation duration over the past few years. Studies to investigate eye movement patterns in reading fluency has also expanded its correlation to aspects such as the configuration of texts and cognitive processes. On the other hand, the second era of eye movement studies corresponded with the behaviorist movement in

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experimental psychology (Rayner, 1998). The focus of the studies were narrowed down and limited research was conducted using eye-tracking in regards to cognitive processes in reading tasks. Meanwhile, in the third era, he further added, marked the evolution in eye-tracking systems which allowed a more accurate and feasible measuring method.

In the 1970s till recent years, the advancement of technology contributed to continuous evolution of technology which made the studies on eye movement during reading more accurate and feasible predominantly on cognitive processes. In his review, Rayner (2009) proclaimed the apparent escalation of cognitive processing exploration in reading as more researchers began to opt for eye-tracking techniques for its readily available and more user-friendly features. Studies in these past few years examined cognitive processes mainly on the levels of phonology, morphology, syntax and semantics. However, there is still a lack of research on eye-movements and cognitive processes including attention and working memory (WM) during reading and majority of the studies focused on patients with dyslexia.

Previous literature reviews have synthesized trends and provided analysis of findings (Affendi Hamat, Haslinda, 2019; Hazita Azman, Mahanita Mahadhir, 2017; Rayner, 1998, 2009; Rasyiqah Batrisya Md Zolkapli, Khazriyati Salehuddin, 2019), but systematic reviews have not been sufficiently carried out in recent years. This review aims to fill the gap in the current research on eye-movements and reading fluency, emphasizing on the gaps in local studies. A literature review and analysis was conducted covering journal publications from 2015 to 2019, encompassing abroad and local articles.

II. RESEARCH QUESTIONS

There is an abundance of published studies that report on various facets of eye tracking studies in relation to reading fluency, for instance, advantages, limitations, and challenges. However, since eye-movements research is emerging, it is imperative to get a comprehensive overview of its advances and influences on measuring eye movement and reading fluency. Below are the research questions addressed by this study within this context :

- What are the trends and breadth and of eye tracking studies in the context of reading fluency in local and abroad studies?
- How far has eye-tracking studies in exploring eye movement patterns in a diverse population and its relation to underlying cognitive processes.
- How efficient are the stimuli designed for the studies in reflecting real-world reading tasks?

III. RESEARCH METHOD

Literature Search Strategy

Relevant publications were searched through the e-journal UKM search tool which contains a variety of databases, namely, Web of Science, ERIC and Scopus. The keywords utilized throughout the search for academic

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journals were “eye-tracking”, “reading”, “reading fluency”, “reading rate” and “eye movement” in different combinations. For instance, “eye-tracking and reading fluency” and “eye movements during reading”. Web of Science was used as the primary database to obtain relevant articles from leading journals, such as *Journal of Cognitive Psychology, Journal of learning disabilities, EURASIA Journal of Mathematics, Science and Technology Education, Behaviour & Information Technology* and *Computer-Assisted Language Learning-Electronic Journal* to name a few. In the second round of search for journals, Google Scholar was used. The reliability and validity of the journals were assured by beginning with contributions published in leading journals, when identifying relevant literature. Accordingly, the articles were manually checked through Web of Science for their journal index and Impact Factor (IF). Furthermore, the articles retrieved were examined in detail for related terms such as “reading”, “reading fluency”, “reading comprehension” in the context of “eye tracking” in the titles, abstracts and keywords. Other than that, relevant articles were further obtained through the references in all of the articles retrieved.

Inclusion and Exclusion Criteria

The articles were chosen based on criteria fixed in terms of the time frame of the studies and the relevance of the studies. The general criteria is the studies must be published from the past five years (2015-2019) and describe about research conducted on reading fluency by measuring eye movement. Besides, the studies must include both researches conducted abroad and locally. The criteria is further narrowed down to studies which report on various aspects of eye-tracking in relation to reading fluency, specifically, the trends, limitations, methods, target population, and future recommendations of the utilization of eye-tracker during reading. Next, studies which describe the applications of eye-tracker in measuring reading fluency among a diverse group of people (e.g. bilingual, dyslexia, poor and good readers) was taken into consideration. Studies which had keywords such as “reading rate” and “reading speed” were also looked into as the terms correspond with the term “fluency” . On the other hand, studies that were excluded were articles published by journals not listed in the Web of Science and do not meet the keywords mentioned previously. Only 20 articles which meet the criteria best were chosen from all the articles retrieved to be reviewed in this paper.

Data Analysis

Content analysis was applied during data analysis which Hsu, Hung and Ching (2013) mentioned in their study that it enables the search for research trends of a particular topic by grouping and analyzing the articles according to their content and shared characteristics.

The 20 articles chosen were tabulated chronologically which helps in identifying the trends from 2015 till 2019. Then, the information extracted were tabulated under categories accordingly - purpose, population/sample, type, method, country context - for comparison. Categorization aids in organizing the studies based on their characteristics. Next, a thorough analysis was done to search for similarities and differences between the studies in terms of trends, target population, type of study, . From the systematic review process, the trends and gaps in this study were acquired.

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IV. FINDINGS AND DISCUSSION

There are a few main findings emerged from the analysis and synthesis of the literature from the 20 articles selected on eye-tracking and reading fluency listed below in terms of trends.

Trends

The articles reviewed were bound within the last five years, from 2015 until 2019, when research on eye-tracking for reading tasks was escalating. As shown in Figure 1, in the past five years, there is a decline from 2015 to 2016 but the number of publications surged in 2017. Despite the sharp decline in 2018, there is a slight increase in 2019. Therefore, this indicate that the research interest in eye-tracking for reading tasks is fairly increasing and constant.

As illustrated in Table 1 (refer to Appendix), the studies in this review utilized varied research methodologies, with a large sum being quantitative in nature through recording, assessments or tests and questionnaire. Only one study opted for a mixed method approach which is the triangulation method and four were qualitative in nature which were systematic review papers. In addition, the table also depicted that 20% of the articles were conducted in UK which is the highest and second to that is USA with a total of 15%, followed by German (n=3). The contributions from other countries should be notable in the field of eye-tracking for reading in these few years, namely, Japan, Turkey, Israel, Malaysia, Austria and Slovenia.

Research on Reading Fluency and Eye-movements in Malaysia

This paper consists of three studies conducted locally. The first study by Ming and Aziz (2019) examined the effects of English as a Second Language (ESL) on students' reading processes. This study used triangulation method in which interviews were done alongside quantitative data from eye-tracking. From the results, it was concluded that English and Psychology students demonstrated similar reading patterns. One of the limitations stated was the study had a small sample size which comprised of Malay students only. The recommendations were to conduct a comparative study of students from various disciplines, ethnics and higher learning institutions to acquire better understanding among Malaysian students as a whole. The second study by Al-Samarraie, Sarsam and Umar (2017) focused on investigating the relationship between column layout and reading performance. The results denote that participants' performance was the best when three-column layout was used for repeated reading. This study contribute to the knowledge of text configurations and reading performance. The third study was conducted by Or-Kan (2016, 2017) to determine the context effects of processing Chinese science terminology. Based on the results, the participants exhibited longer first fixation and gaze duration for science texts compared to corresponding texts (Sarah Yusri & Or-Kan, Soh, 2019). The author suggested that to apply the research in other languages to examine cognitive differences in processing contextual effect. Overall, these studies contribute to the existing

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researches and knowledge on the utilization of eye-tracking in reading which can be pioneer studies for future research especially in Malaysia (Hamidah, Farah, Maslizah, 2019).

Diversity in Population Background

Overall, the population in the studies in this paper comprised of participants from across all ages, from children to elderly. Based on Figure 2, it is apparent that children (n=7) is the largest population target among the studies, then followed by undergraduates (n=6) and adults (n=5). The data concludes that eye-tracking researches on reading fluency has covered these group of population more extensively than other populations. Therefore, eye movement patterns during reading among these group of populations can be generalized better given the adequate data and evidence provided by the studies. Eye-tracking data from the studies (Joseph, Bremner, Liversedge & Nation, 2015; Gagl, Hawelka, & Wimmer, 2015; Wonnacott, Joseph, Adelan & Nation, 2016) suggested that children, both good and poor readers, establish regressions and rereading directly from the pronoun region and exhibited discourse-level information sensitivity when reading. Besides, the effects relating to gender information only applied to good readers, whereas for poor readers, there was a substantial contrast evident in terms reading efficiency , specifically for regression probability and total reading time . On the other hand, studies (Barnes, Kim, Tighe & Vorstius, 2017; Franken, Podlesek & Možina, 2015; Murata, Miyamoto, Togano & Fukuchi, 2017; Radha, Ruzy Suliza Hashim, Ruhizan Mohammad Yasin, 2018) in adult populations proved that adults manifested similar reading behaviour as children whereby a direct comparison between typically developing young and struggling adult readers revealed relation of underlying patterns of strength. Next, adults also showed increase regressions during anaphor processing from the post-anaphor region like children but with the distance effect greater in adults. For undergraduates, commonly, proactive readers manifested longer saccades and more regressions while conservative readers were seemed to present short saccades and fewer regressions; and there was a high rate of pronoun skipping behaviour (Schuster, Hawelka, Hutzler, Kronbichle & Richlan, 2016)

Moreover, the population of the studies are usually monolinguals or native speakers of a language. As illustrated in Figure 2, a minute study used non-monolinguals speakers as their participants with only two and one studies for bilingual and multilingual speakers, respectively. Studies on reading fluency using eye-tracking has also included special needs participants, but the studies only encompassed patients with dyslexia (n=2), aphasia (n=1) and glaucoma (n=1).

Research on The Relation of Eye Movements With Underlying Cognitive Processes

Research on underlying cognitive processes for reading fluency begin to emerge more rapidly with the availability of other technology such as electroencephalogram (EEG) and Functional Magnetic Resonance Imaging or functional MRI (fMRI). For instance, Schuster, Hawelka, Hutzler, Kronbichler, and Richlan, (2016) in a study utilized a combination of eye-tracker and fMRI to investigate the effects of length, frequency, and predictability on word level and brain responses. The research obtained crucial discoveries with regards to eye movement patterns and underlying cognitive processes. For example, the study was able to examine in further on the exact nature of

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visual attention during natural reading from brain responses in relation to eye movement patterns, specifically on skipping behaviours. In another study by Alptekin and Erçetin (2015), the link between eye-movement patterns and working memory functions in L2 participants was investigated. The data showed that storage capacity and fixation durations was unparalleled within the critical region of the sentences. Furthermore, regressions initiated from the sentence-final region had negative correlation to both storage and processing performance. This particular study has added extra knowledge into this research field whereby the findings denote that eye tracking technology has the potential to measure online time-course of processing and storage components depicting working memory operations and L2.

Efficiency in Reflecting Real-World Reading Tasks

From the analysis of reading fluency research conducted through eye movement studies, the majority of studies conducted focused on phoneme, word and unconnected sentence levels, perceptual span, fixations and skipping which do not reflect how reading is carried out in the real-world. Barnes, Kim, Tighe and Vorstius (2017) revealed that most of the studies measured at the lexical level of reading, the perceptual span, word skipping, fixation durations and regressions which supports the nature of current stimuli used in the studies. Out of 20 articles, only two of the studies used stimuli which resembled real-life reading materials. Jarodzka and Brand-Gruwel (2017) stated that eye movement patterns differed according to the tasks. It was revealed that when reading for comprehension, words which occurred less frequently were fixated longer but was not the case for proof reading for spelling mistakes. Therefore, this prove that the task influences cognitive processes as well as visual processes. Nevertheless, they expressed that resembling real-world reading reduces the aptness to conclude from eye-tracking measures on cognitive processes during reading.

V. CONCLUSION

This paper reports a systematic literature review comprised of 20 relevant articles on eye-tracking and reading fluency in the context of abroad and local studies among different population background. Findings are inferred from analysis and synthesis through the content analysis method. Six main findings emerged throughout the analyis. First, this review paper deduced that there is a fairly constant interest in trend for incorporating eye-tracking in measuring eye movements during reading, with contributions from studies conducted around the world. Second to that, this paper revealed the inefficiency to generalize findings obtained to real-word reading tasks. Third, there is a scant studies on population from diverse backgrounds. Fourth, there is a lack of studies which report on the relation between eye movement patterns and underlying cognitive processes. Finally, there is a scarce of eye-tracking studies conducted locally. As researchers begin to recognize the potential of eye-tracking devices in measuring and understanding eye movement patterns during reading tasks, the utilization of eye-tracking on diverse population is

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timely in light of growing interest. Overall, this paper presents findings, limitations as well as future recommendations to help researchers in carrying out more extensive and comprehensive studies.

VI. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH AND PRACTICE

This paperhighlights a number of critical future recommendations for further researches pertaining to eye-tracking and reading fluency.

Longitudinal Studies With Greater Sample Size

It can be deduced that there is a necessity in future researches to move toward studies conducted on a greater sample of population and longitudinal evaluations. Majority of the studies, based on this review, have conducted cross-sectional studies with only one study (Eilers, Tiffin-Richards & Schroeder, 2019) opted for a longitudinal evaluation. As many studies chose the cross-sectional method, the efficacy of the research in a wide range of methods is apparent. However, the conclusion leads to the questioning of generalization effectiveness whereby the effectiveness of the research methods were unable to be applied to a larger group of sample. A long-term study of eye-tracking technology has a potential to provide crucial and important inputs about the efficacy of this technology for supporting reading skills. Hence, it is essential to carry out more longitudinal studies with a greater sample size to determine the suitability of the eye-tracker technology with constant changes over time in reading skills development.

Attention to Diversity and Special Needs

Generally, the studies compared among the same group of background but with different levels of reading abilities. A majority of the studies focused on monolingual speakers, English as the medium and typically developing population. Therefore, there is a need to undertake more research on measuring reading fluency through eye movement involving different background of populations to corroborate existing findings. Some of the populations mentioned in the articles reviewed were adult with basic education (Barnes, Kim, Tighe & Vorstius, 2017), glaucoma patients (Murata, Miyamoto, Togano & Fukuchi, 2017), participants from diverse races , disciplines and ethnic origins (Ming & Aziz, 2019), readers with impaired eye-sight (Franken, Podlesek & Možina, 2015) and participants with different educational level (DeDe, 2017; Humaira Raslie, Yuen, 2017). Future research on special needs population is essential as it is a good option for supporting therapy processes. In addition, different age groups and language skills have dissimilarities which require more research evidence. Hence, studies on diverse populations is important as it may contribute to this research field in which the findings can be implemented and transferred across all populations.

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Natural Reading Behaviour and Environment

More than half of the studies reviewed used silent reading method over oral reading, but the direction needs to change. Barnes, Kim, Tighe and Vorstius (2017) stated that oral reading require more research as reading aloud and reading silently are dissimilar and may readers including those with high reading fluency do tend to read aloud. They further mentioned that oral reading is useful as it disclose important reading processes information, especially for low-skilled readers.

The nature of the research should also progress towards natural-like reading. Most research on reading fluency through eye-tracking focused on single words or sentences representation which do not reflect real-world reading. Based on a review by Jarodzka and Brand-Gruwel (2017), it is important to understand reading processes using multiple resources as in real-world tasks. They described that "although we read words and sentences, we nowadays read for multiple purposes and from all kind of sources" (p. 193). Hence, studies should also be directed towards natural reading.

Studies Using Different Languages

Out of 20 articles, English was the medium of language measured for nine articles, both for native speakers and bilinguals. Studies with different languages were limited. Four studies were conducted in German (Gagl, Hawelka & Wimmer, 2015; Eilers, Tiffin-Richards, & Schroeder, 2019a; Eilers, Tiffin-Richards, & Schroeder, 2019b; Schuster, Hawelka, Hutzler, Kronbichle, & Richlan, (2016); one in Japanese (Murata, Miyamoto, Togano & Fukuchi, 2017), Turkish (Alptekin, & Erçetin, 2015), Hebrew (Jaffe-Dax, Frenkel, & Ahissar,2017), Chinese (Or-Kan, 2017), and Slovene (Franken, Podlesek & Možina, 2015). Murata, Miyamoto, Togano and Fukuchi (2017) expressed the lack of studies in Japanese as one of their limitations while Ming and Aziz (2019) asserted the need to include different races and ethnics in Malaysia to contribute to the studies on different languages. Inclusion of different languages in studies is beneficial as it can provide a more comprehensive understanding of those languages such as, the grammar, vocabulary and syntax of a language. Inadequate previous evidence for studies on a particular language reduce the significance of the findings due to lack of reliable and valid data as support. Therefore, the direction of future studies should consider using other languages to apply the benefits of eye-tracking into non-English languages, besides to substantiate existing studies.

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