Using Eye-tracking technique to design innovative learning material in Medical Education: Autonomic Pharmacology as an example.

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Abstract

Aim:

A wide range of research has shown that knowledge retrieval practise results in improved retention. Does providing illustrations (containing an image and words) on a t-shirt enhance learning? And is this knowledge retained after a short(1 week) or long (1 year) delay?

Method:

A two-phase study was conducted, the initial phase used eye-tracking technique to compare the “image” and “word” attractiveness of two Autonomic nervous system (ANS) pharmacology learning materials on non-science students, the interventional phase used a pre, post and retention test to measure memory, application and lecture learning from a learning material printed on front and back of t-shirt.

Results:

Total Fixation Duration (TFD) on the 'Image' (3.96 ± 1.12 seconds) as the Area of interest (AOI) was longer compared to Design (2) (3.43 ± 0.87), ($t = 36.52$), $p > 0.05$. On the contrary, Design (2) had longer TFD (1.24 ± 0.52) on the 'Words' AOI compared to Design (1) (0.99 ± 0.64), t-test ($t = 37.48$) $p > 0.05$. Design (2) attracted the students' eye gaze for both “Image” and “Word”, therefore, design (2) was selected as learning stimulus for the second interventional phase, students completed a pre-test knowledge test, they were then exposed to the t-shirt designs for a week before completing a post-test 1 week and retention 1-year later to see if there is evidence of better retention of ANS pharmacology knowledge. Repeated measures analysis demonstrated a significant recall of knowledge ($F(1.987, 162.9) = 20.53$, $p < 0.01$). Mean of recall pre-test question (2.12 ± 0.15), recall post-test (3.36 ± 0.16) ($p < 0.0001$) and retention (1-year) (2.7 ± 0.14) ($p < 0.01$). Application and lecture-related questions showed no significant differences at pre, post and retention tests.

Conclusion:

Eye-tracking is useful in designing learning material and ANS pharmacology knowledge retrieval outside the class was associated with a significant improvement of long-term memory as such this might be a promising method in medical education.

Keywords: ANS pharmacology; eye-tracking, multimedia principle, memory, retention

Introduction

Eye-tracking is a useful educational tool to capture learner's attention and memory by measuring learner's eye movement and gaze. It is becoming more readily used as it can provide unique insights to processing underlying learning process and interest in how multimedia sources can be used to enhance learning (Scheiter et al., 2018). In medical education, the use of eye-tracking technology is increasing and a recent systematic review found 33 studies in areas of medical training that applied eye-tracking techniques (Ashraf et al., 2018). The applications of eye-tracking mostly were related to teaching and training, or competency assessment of radiographic abnormalities, ECG readings, and pathological or surgical findings (Ashraf et al., 2018).

Kok and Jarodzka (2017) claim that the interpretation of (eye-tracking indices relates) to a cognitive process within a medical education context; the relationship must be based on a theory-guided research question, clear variables and measurements in the design of the experiment and, triangulation of research methods (Kok and Jarodzka, 2017). However, in cognitive psychology, there are extensive researches linking the oculomotor activity in eye movement to the hippocampal area, the primary site of memory; and demonstrated that previous memory could guide the eye movement to prioritize the representation of the visual knowledge even in the absence of verbal instruction (Ryan and Shen, 2020). Hannula (2018) used eye-tracking technique to illustrate the relationship between eye movements, attention and long-term memory gains in learning. The results showed that long, purposeful fixation of eyes at a picture is associated with long-term retention of that picture, the memory retrieval is greater when these eye fixations are distributed to-parts of the picture (Figure 1) rather than a prolonged fixation to a localised focus on the picture (Hannula, 2018).

Key concept(s) are often accompanied with an image in learning materials available in books, websites and learning apps to help students in understanding the materials (Mason et al., 2016) (Mason, Plucino&Tornatora, 2016, Seufert, 2019). Using images is a valuable pedagogical tool, for the learner, combining the information from two different presentation styles or channels, i.e. having both text and pictures can help integrate complex information and hence making links clearer in the learner's mind (Ainsworth, 2006, Hosler & Boomer, 2011). The use of text and images can be an effective tool to convey difficult concepts and improve students' engagement with the material (Hosler& Boomer, 2011). It has been known that long-term memory has unlimited storage capacity of information constructed in mental representation (schema) (Young et al., 2014). This higher quality and better organisation of information is associated with a coherent working memory load (Young et al.,

2014). A prompt retrieval of the information is transferred to long term memory and allows learners to reconstruct the materials given to them (Smith et al., 2016).

According to the cognitive theory of multimedia learning (Mayer, 2005), developing an instructional learning material that fosters the learning must involve mental processing of dual channels of information (pictures and words) (Jarodzka et al., 2017). Thus, the integration of the new information with prior knowledge information in long-term memory depends on how the learning material graphical illustration is selected and explained with appropriate text or verbal information to be organised in pictorial and verbal cognitive models of the working memory (Mayer, 2002).

Autonomic nervous system (ANS) pharmacology is considered a core but basic knowledge for health care disciplines. The students are required to retain core subjects to at least clinical years. Designing suitable materials to understand the impact of illustrations on student learning and engagement is key (Farinella, 2018). In our pilot study to teach ANS pharmacology, we used eye-tracking technique to create illustrations (images and words) to study their impact on knowledge accumulation and retention. The findings were associated with significant improvement on recalling and application of ANS pharmacology. However, limitations include small sample size, some images within the illustration having prolonged eye fixations, and less time directed to the text associated with the image (Alshagga et al., 2018). Therefore, this study aims to conduct an eye-tracking experiment to design a learning aid that will be used as intervention in teaching ANS pharmacology.

Method

Study design, Setting and sampling

This was an experimental study that was conducted in two phases at a Malaysian university, over the period between 2017-2019. During the first phase, a within-subject design was used with Design (Word vs Image) being the within-subject factor. The dependant variable was total fixation time measured in milliseconds (ms). A between-subjects design was used to investigate which design resulted in better performance, assessed by multiple-choice questions related to the design printed onto t-shirts. The first phase was conducted to guide intervention phase which is tested in this study and is described in the following section.

To measure the impact of the learning material during the second phase (intervention phase), a within-subjects design was used with Performance (Pre-test vs 1 week delay vs 1 year)

being the within-subjects factor. The dependent variable here was the accuracy of which the 2 population participants, i.e. Medical students and Pharmacy students, full details of these participants is reported next section, answer the multiple-choice questions. The study was completed over three academic semesters during the academic years 2017-2019.

Participants

First phase recruited 48 non-Science participants (aged 18-23; females =32) (No need to report the name of the university, just write Malaysian University, it is reported above under study setting). Participants were randomly divided between subjected to either Design (1) or Design (2). Each group composed of 24 participants (female 16, male 8). All were proficient English speakers, with either normal or corrected-to-normal visions (self-reported?). Each participants was given incentive of five Malaysian Ringgit for 5 minutes eye-tracking experiment.

The second phase involved Year 1 Medical (n=83), Year 2 Medical (n=92) and Year-2 Pharmacy (n= 69) students. Only Year 1 Medical students was tested for three tests; pre-test, post-test (1-week interval) and retention (1-year interval) (Why), while Year 2 Medical and Pharmacy students were exposed to only the pre-test and post-test (1-week interval).

Visual learning stimuli

All participants who took part in the initial phase were not studying science related-courses. This selection criteria was to eliminate any prior autonomic nervous system (ANS) knowledge influencing the experiment. This was to ensure that the stimuli would be suitably engaging regardless of non-science students' background. Eye movement data was collected using a TOBII eye-tracker (T120); TOBII Studio 3.0.3 software was used to create the experimental programme. The details of the eye-tracking software method is described in a previous publication (Alshagga et al., 2018). Briefly, students were randomly assigned into two groups; namely (Design 1) and (Design 2). Each design was tested on 5 trials of 5-stimuli, consisting of 5 image-words featuring a body organ and name of a drug and receptor. The size of each image is 300 pixel (W) x 160 pixels (H). Three Area of Interests (AOIs) is determined, namely, Whole Image, Whole words, and Whole Image and Word (Figure 2A). Instructions appear on the screen briefing students on what the task entails. A white fixation cross appears in the centre of a black background (Figure 2B) for 0.5 seconds, followed by

either Design 1 or Design 2 for 1second. Participants are instructed to feel free to look at any point on the screen for those brief breaks. At the end of the eye-tracking test, participants completed 3-MCQs test measuring the participant's recall ability of paired image-word. The test was done after 1 minute of the eye-tracking task. The design of ANS pharmacology which recorded higher total fixation time on both image and word, as well as higher correct scores on the test after eye-tracking, was selected and printed on t-shirts. The frontal side of the T-shirt show an organ and agonist drug, and the back show the same organ but with the associated antagonist.

Interventional phase

The experimental group in this study was Year-1 MBBS, who wore ANS pharmacology t-shirts for a week. Year-1 MBBS students had completed all lectures (3 lectures, drug names, receptor and organ presented in tables) on ANS pharmacology on the day of the intervention. Year-2 MBBS had completed their ANS pharmacology two semesters before our study, while Year-2 Pharmacy students completed ANS pharmacology one semester before taking part in the study. MBBS students in Year 1 and Year 2 have a break time from 10:00 -10:30 am. Pharmacy break time 11:00-11:30 am. Therefore, Year-2 MBBS were more likely to have greater exposure to the visual stimulus on the t-shirts wore by Year-1 MBBS during breaks compared to Year-2 Pharmacy. Even though this plan was unintended, it might serve as a control condition due to the potential of repetitive pre-test post-test bias on the measurement. To capture the effect of the intervention, we added some questions at post-test to explore the number of Year-2 students who were exposed to the t-shirts and for them to provide feedback on this approach.

All MBBS and pharmacy students were asked to answer a pre-test composed of 15 multiple-choice questions (MCQs, is it online or paper pencil?) about ANS pharmacology before the intervention. The MCQs were modified from the United States Medical Licensing Examination (USMLE) designed to measure recall (5 MCQs), application (5 MCQs) and general pharmacology (5 MCQs). Recall and application questions have a relation to the images and words on the t-shirts, while the general questions have more relation to the lecture notes. Three pharmacology lecturers were on consensus regarding the question selection used.

Immediately after the pre-test, each Year-1 MBBS student was given the T-shirt and asked to wear the t-shirts for a week during working hours. All MBBS and pharmacy students completed a post-test after a week. The students were unaware about the time of the post-test, nor were they expecting to sit for the same pre-test questions. On the first semester of the academic year 2018-2019, when Year-1 MBBS students transferred to Year-2, a retention test was conducted. The retention test questions were identical to the pre-test questions.

Ethical considerations

Ethics approval was obtained from the University of Nottingham Malaysia, Science and Engineering Research Ethical Committee (MA270614) and date (d/m/y). Participants were required to provide informed consent prior to volunteering in the different sets of experiments and were made aware of their right to withdraw from the experiment at any time, with or without explanation. Participants are guaranteed complete anonymity with strict confidentiality.

Statistical analysis

Mean ($\pm$ SEM) was used to measure Total Fixation Duration (TFD), Paired and independent T-tests were used to compare within and between groups, the differences between two quantitative measurements. One-Way ANOVA repeated measure analysis was carried out to analyse score changes over time. All analysis employed a significance level (p-value) of ≤ 0.05 and the Statistical Package for the Social Sciences (SPSS 20) was used for data analysis.

Results

Design selection phase; Eye-tracking findings

The findings revealed that students exposed to Design (1) had longer TFD on the 'Image' (3.96 ± 1.12) of Area of interest (AOI) compared to students exposed to Design (2) (3.43 ± 0.87), with $t(36.52) = 1.98$, $p = 0.06$. On the contrary, students exposed to Design (2) had longer TFD (1.24 ± 0.52) on the 'Words' AOI compared to students exposed to Design (1) (0.99 ± 0.64), with $t(37.48) = -1.20$ (-?), $p = 0.24$ but this difference was non-significant. See figure 3 for the TFD of each design and AOI results. Analysis of the memory test immediately after the eye-tracking experiment showed 58% of participants in Design (2) have

correct answers compared to 42% in Design (1). Based on the above findings, we found that Design (2) was more attractive and informative for learning "image" and related "words" than Design (1); therefore, Design 2 was printed on t-shirts, to be used for the intervention phase of study.

Year-1 MBBS students' learning before and after the t-shirt intervention

Eighty-three (83) students participated in the study till academic year 2018-2019, with a drop-out of 14 students due to unknown reasons to the researchers. During the intervention week, an average of 86% of students wore the t-shirts in classes. Results of Year-1 MBBS performance are shown in Table (1) and Figure (4). Repeated measures analysis revealed that assessment of students on recall questions (5-MCQs) related to the visual stimulus on the t-shirt raised significantly ($p > 0.001$) from a mean pre-test score (2.12 ± 0.15) before the intervention to post-test score (3.36 ± 0.16) after a week of wearing the t-shirts. After the post-test, students were unable to wear t-shirts during official hours due to university dress-code restrictions. Measuring the retention of knowledge in the next academic year showed a decline in students' performance (2.7 ± 0.14). However, the recall ability after a year was significantly ($p < 0.01$) higher than the pre-test score.

Intervention-related application questions and lecture note-related general questions showed a small increment in post-test performance after a week of intervention and a decline in performance after a year. However, the repeated measures analysis did not reveal significance on application and lecture-related questions before or after the intervention (See Figure 4).

Calculating the percent (%) of knowledge gain after the intervention by subtracting the knowledge in the pre-test before the intervention gives better information on the impact of the intervention on students knowledge. The knowledge gain was (55%) and (44%) for post-test and retention (Figure 3). Paired t-test showed insignificant differences ($p = 0.346$) between the two measures.

Impact of intervention on Year-2 MBBS and pharmacy students ANS pharmacology learning

Recall performance was significantly improved amongst Year-2 MBBS students from a mean (1.2 ± 0.1) pre-test score to (2 ± 0.1) post-test, with $t = 4.4$, $p < 0.001$ (See Figure 5)., whilst Year-

2 BPharm pre-test score (2.61 ± 0.14) and (2.64 ± 0.15) at post-test, with $t = 0.14$, $p = 0.892$. On application questions, a surprisingly non-significant post-test drop was observed in Year-2 MBBS from (2.3 ± 0.1) to (2.1 ± 0.1). While Year-2 BPharm showed minor improvement on application post-test (2.7 ± 0.1) compared to pre-test (2.5 ± 0.1). However, the difference was statistically non-significant. Both MBBS and BPharm showed quite similar results on knowledge of ANS pharmacology related to lecture note (See Figure 5).

Self-reported survey on interaction with this intervention showed approximately 57% of Year-2 MBBS students indicating they had seen the t-shirts worn by Year-1 MBBS, compared to 23% of Year-2 BPharm. Fifty percent of MBBS Year-2 students agreed that the t-shirts stimulated them to talk or read about ANS pharmacology compared to 32% BPharm students. Many students found it very stimulating and exciting to have a summarised version of key information on ANS pharmacology.

Discussion

The aim of this study was three-fold, how eye-tracking technology can be applied as an educational investigative technique, how exposure to multimedia materials can help integrate complex materials and how retrieval practise can be used to measure retention. Autonomic nervous system (ANS) pharmacology provides a fundamental understanding of clinical pharmacology. Many teachers innovate various pedagogical methods to improve pharmacology learning in medical (Richir et al., 2008), pharmacy (Richardson and Maddock, 2013) and nursing (Thomas and Schuessler, 2016) curricula. Designing a learning aid using an eye-tracking investigative technique is an innovative approach. Eye-tracking has the potential to help understand how information contained in words and images can be combined to provide a coherent mental model of the content covered in a classroom or lecture hall setting.

Mayer's principle of multimedia learning postulates that students learn better when new knowledge is presented by visual and verbal information. When multimedia principle is applied in a surgical curriculum, it had been found that slides containing images and words were associated with significant short-term knowledge retention and transfer compared to traditional word-only/rich teaching slides (Issa et al., 2011). We have also reported

improvement in memory and application in our previous study (Alshagga et al., 2018) when the intervention was two weeks long.

In the current study, although, our eye-tracking results showed no significant difference between the two designs (Design 1 and 2), Design 2 was associated with higher correct scores from students who have never been exposed to ANS pharmacology. Thus, when a picture of an organ response was integrated to a drug name, this is consistent with the spatial contiguity principle of integrated presentation of text and image (Mayer and Moreno, 2003). The non-science student's eye gaze is more likely to hold both aspects together in the working memory and is integrated into working memory as those students scored better in the memory test immediately after the experiment. This shows that using illustrations can convey complex information and make them not only more engaging to non-science students but also has the potential to make the information more accessible (Farinella, 2018).

The impact of the visual stimulus of the t-shirts was also evident in medical students post-test which showed a significant improvement in recall questions at the post-test compared to the pharmacy students who claimed less exposure time to the intervention. The degree of prior knowledge could explain why they showed significant improvement in the recall questions, so what we found could like be an enhancement effect. This suggests the use of the t-shirt provided a sufficient cue to support meaningful learning. Previous research has shown that retrieval practice can enhance learning of information presented regardless in a classroom or large lecture halls (Smith et al., 2016). Retrieval practice has shown to help retention of information from a number of sources, such as short text materials, pictures, and video lectures (Butler and Roediger, 2008; Roediger III and Karpicke, 2006; Wheeler and Roediger III, 1992).

In our previous 2- week long study (Alshagga et al., 2018), we divided biomedical science students into an experimental group (t-shirts), and a control group with the traditional teaching of ANS slides showing tables of organ names and type of receptor agonist and antagonist. There was a difference in the pre-test results in favour of the experimental group that probably indicates more interest in the subject. However, after a two-week duration of wearing t-shirts by both groups, there was no difference in memory and application knowledge between the two groups. In this study, the performance of the application questions did not reveal a significant difference. Therefore, we postulate that duration of exposure to stimulus may have an impact on the application of the information in problem-

solving. Based on the anecdotal reports, the use of the t-shirts were effective in engaging students' attention and could have motivated students to process the material more deeply.

In this study, we opted to include all Year-1 MBBS students as an experimental group and compare them to Year-2MBBS and BPharm and allow the experiment to run without distraction to the timetable. The score differences of each cohort might reflect the time lapse since the study of ANS pharmacology. However, our data revealed that memory is the aspect of learning that have had improved significantly after repetitive exposure to the visual stimulus for ANS pharmacology.

The current study has presented the use of eye-tracking in designing an attractive ANS pharmacology learning material on t-shirt to allow retrieval of knowledge, which probably could be added cost to teaching. If this was the case in most educational institutions, the learning design could be used in preparation of lecture notes or wall posters in class instead. The knowledge gained from this intervention is difficult to be separated from repeated exposure to the same practice test questions, preparation for examinations, and impact of lectures. However, the findings stimulate future research to be carried out

Conclusion

The study concluded that using eye-tracking as part of designing learning material is an innovative way to teach ANS pharmacology and allows knowledge retrieval outside the class. The designed learning material was associated with a significant improvement of long-term memory for medical students who were exposed to the intervention.

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Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

Author contribution

MAA, AYLL, HKN, JP and AH designed the study.

MAA, ASO, SAR prepared the question-test.

AYLL and JP performed the experiment& data analysis of eye-tracking.

AYLL, HKN, AKA, ASO and SAR performed the intervention.

MAA, AYLL, HKN and IAI analysed the data.

MAA, AH and IAI secure the grant

MAA& JP drafted the manuscript. AHclarified text and edited the English language. .

SK edited, critically commented and approved final draft of the manuscript

OH edited, critically commented and approved final draft of the manuscript

All authors read and accept the manuscript.

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Figure 1: The multiple eye fixations on picture details and features as shown in red boxes and circle.

A

Design 1

Design 2

B

Figure 2: A. The two autonomic nervous system designs used in eye-tracking with Area Of Interest "image" yellow square and "words" blue squares. B. Diagrammatic representation of the sequence of the eye-tracking experiment, each trial consisted of participants looking at the fixation in the centre (+) of the screen before the pair of experimental items appeared for 1 second.

Figure 3: Total Duration of Fixation (TDF) in milliseconds (ms) for "image" and "words" in each design expressed in Mean $\pm$ SEM. Each design (n=24); * P -value < 0.05.

Table 1: One-Way **ANOVA** repeated measures of students' performance on an Autonomic Nervous System (ANS) test after t-shirt intervention.

Recall questions (T-shirt-related)	SS	DF	MS	F	P-value
Intervention (between columns)	64.07	2	32.04	F (1.987, 162.9) = 20.53	$P < 0.0001$
Individual (between rows)	223.9	82	2.73	F (82, 164) = 1.75	$P = 0.0013$
Residual (random)	255.9	164	1.561		
Total	543.9	248			
Application questions (T-shirt-related)					
Intervention (between columns)	7.357	2	3.679	F (1.905, 156.2) = 3.078	$P = 0.0513$
Individual (between rows)	129.7	82	1.582	F (82, 164) = 1.323	$P = 0.0662$
Residual (random)	196	164	1.195		
Total	333	248			
Lecture note related questions					
Intervention (between columns)	4.586	2	2.293	F (1.955, 160.3) = 1.979	$P = 0.1427$
Individual (between rows)	101.3	82	1.235	F (82, 164) = 1.066	$P = 0.3613$
Residual (random)	190.1	164	1.159		
Total	296	248			

SS= Sum Squares, DF=Degree of Freedom, MS=Mean Square, F=ANOVA value.

Figure 4: Repeated measure analysis of Year-1 MBBS students' performance on Autonomic Nervous System (ANS) test over three academic semesters and percentage of knowledge gain. (n=83); * P -value < 0.05, **** p -value < 0.0001.

Figure 5: Comparison of pre-test and post-test scores in Year-2 MBBS and Year-2 BPharm. (n=92 MBBS, 69 BPharm); * P -value < 0.05 , **** p -value < 0.0001 .