Do Online Search Processes Vary by Task Complexity? An Eye-Tracking Study

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Abstract—**This study examined whether individuals seek information online with different purposes and requirements in different ways. By analyzing eye-tracking data by varying levels (i.e., search activity, cognitive process and search patterns), the findings confirmed again that the processes individuals searched for information online differed by the complexity and nature of the search task. Significant differences were observed in eye fixation duration in searching and eye fixation count in searching, as well as time in planning. Future studies can attempt to collect more data with a larger sample and a wider range of different tasks in a naturalistic setting to help improve our understanding of how search task types affect search process.**

Index Terms—**Online search, eye-tracking, type of search tasks.**

I. Introduction

The Internet has emerged as a widely used tool for information seeking in various fields including online purchase [1], health [2], news and politics [3], science [4] and so forth. However, such information is not always easy to be found online. On one hand, the online search process has been proved to be a cognitive and metacognitive problem-solving process [5]. Searchers need to generate effective keywords relevant to their queries, evaluate the relevance of the results provided by the search engine, and then select one or more web pages to find the required information. If the search engine does not provide expected results, the information searching activity becomes even more complex: the individuals have to reformulate their first query by adding and/or removing keywords and possibly modify their search strategies. Reformulating unsuccessful queries is a highly demanding task, which involves control processes [4], [6].

On the other hand, other factors have also been found that could make the search process different, such as searchers' age [4], gender [7], emotion [8], and cognitive style [9]. Besides the individual characteristics, the type of search tasks has been examined in different search contexts. Researchers tended to categorize the search tasks in different ways, by complexity [4], by the ease of task interpretation [10] or by the nature of the search task [11]. The samples also varied from primary school children to graduate students. In general, these researchers unanimously agreed that the type of search tasks did affect online search behavior. In this study, I examined whether and how online search processes differed by task complexity in Chinese university students.

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II. Related Literature

In recent years, more and more studies have adopted the eye-tracking method as a way of analyzing online search behaviors (e.g., 10, 12-16). Some of these studies focused on certain stages of online search, such as information evaluation [12], [13]. Some researchers took a process perspective on online search by looking at strategies used throughout this process [4]. Others investigated the effectiveness of online tools that facilitated online search [10]. Despite various purposes in these studies, they all proved the effectiveness and efficiency of using eye-tracking techniques to re-capture this dynamic, adaptive, and reiterative process.

Among the studies that examined factors influencing online search processes, eye-movement data also lent great support to locate these factors, among which type of search task has been repeatedly examined. For example, reference [10] reported that online search patterns changed according to types of tasks. Specifically, users generally applied linear scanning (both backward and forward) at the ready-to-use task, nonlinear scanning at the easy-to-interpret task, and mixed scanning (combination of backward and forward) at the hard-to-interpret task. Reference [14] also found that several search behaviors, including task completion time, information source relevance evaluation time, and eye fixation varies by different task characteristics.

However, there are two concerns about these studies. First, a scrutiny of these studies showed inconsistent ways of categorizing different tasks, such as by nature (navigational vs informational, e.g., [15]), difficulty level (simple vs difficult, e.g., [4]), cognitive level (high vs low) or content (report vs trip, e.g., [11]). This increases difficulty when we want to compile and compare research findings across studies. Second, researchers tended to view the online search process in different ways. Some tended to consider the search process consisting of specific behavioral activities with varying fine grain levels, such as search query input, viewing searching results, organize and present information [16], or aggregation, discovery and synthesis at a coarser level [17]. In contrast, others consider the search process at a cognitive level from a self-regulatory perspective, such as planning, evaluating and controlling [4].

III. Present Study

To further our understanding of how the types of search tasks are related to online search processes, and meanwhile to address the concerned identified as above, I tended to integrate the previous studies in two ways. First, the type of search tasks can be classified based on the complexity level as well as the nature of the task. To this end, three search

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tasks were employed in this study to cover both dimensions of task type: Task 1 and Task 2 were both information-based problems, with different levels of complexity. Task 1 was simpler in the sense that it required less cognitive load, the question was more straightforward (namely, less chance to misinterpret the question) and the answer was relatively easier to be found on the Internet, compared to Task 2. Task 3 was an argument-based problem which required participants to gather evidence online for both sides and construct an argument with collected information sources. Table I presents the different facets of three tasks in this study.

TABLE I: THE CHARACTERISTICS OF SEARCH TASKS

	Task question	Nature of Task	Complexity Level
Task 1	After you clean a glass with tap water, why are there always some water drops remaining in the glass surface?	Information-based	Low
Task 2	In what way do bees decide where to build new homes?	Information-based	High
Task 3	In many countries, vaccination has been listed as one of the requirements for new student recruitment in primary schools. Do you agree and why?	Argument-based	Moderate

Second, the examination of online search processes can employ data at both the behavioral activity and cognitive activity level. Reference [4] identified three (meta) cognitive processes involved in online information search activities using a search engine: planning, evaluating and controlling. In the planning process, individuals need to understand the task requirement, or develop a search strategy. This cognitive process typically takes place in the first search query formulation activity. In the evaluating process, individuals process and assess relevance of information returned by each round of search. This process typically takes place in the activity of scanning search results and reading selected webpages. The controlling process occurs when the previous round of search does not provide any relevant result(s). This metacognitive process typically takes place in the activity of revising search queries. To examine these three processes, data can be collected and analyzed at both levels to provide a fuller picture of how individuals search online with a particular purpose and task.

IV. METHOD

A group of 12 students from a public university in Macau (41.67% females, mean age was 22.75 years old) participated. The participants were requested to conduct three different web searches in a computer lab. The search tasks were designed to be representative of common search tasks on the Web, varying in difficulty and topic (see Table I). The first two tasks were information-based, varying in their complexity, and the third task was argument-based.

All participants used IE as the web browser and Bing as the search engine. They were allowed to finish the task in their own paces. A TOBII Pro X2-30 remote eye tracker was used for eye movement data collection. Several indices were used as indicators of ocular behaviors. First, eye fixations are defined as a spatially stable gaze lasting for approximately 200-300 milliseconds [18] in areas of interest (AOI). I defined three AOIs for each screen within each task and participant: the search box area, search result page and selected webpages. For each AOI, I computed eye fixation duration and frequency count, to measure each type of search activity from different aspects. Second, scanpaths were used to reveal eye-movement patterns which connected saccades and fixations. They depicted a complete sequence of fixations and saccades within different AOIs. In addition, another non-gaze-related behavioral measure was adopted: total time spent on task (measured from the input of the first search query until participants completed the search process).

The statistics for each type of activity was computed by the TOBII Pro Eye Tracker. For the data analysis at the cognitive level, time in planning was measured by the time a participant spent from receiving the search task until he or she finished constructing the first search query. This was reflected by the measure of “time to the first fixation in the search result page”. Time in evaluating was measured by the total time spent on viewing search results and accessing selected webpages. Frequency of controlling in this study was measured by the number of times a participant revisited the search box to re-examine his or her search query.

V. RESULTS

A. Eye-Movement Measures of Search Activities by Task

Table II presents the overall search process at the behavioral activity level measured in time or fixation duration in each task by all the participants. The variable of “time spent in searching” for Task 1 and “time spent in planning” for Task 2 and 3 showed very high positive kurtosis and were thus transformed by the log10 function. After the log10 transformation, all the variables showed acceptable skewness and kurtosis values. Repeated measures ANOVA was then used to analyze the search activity data to compare the difference in the search activities across tasks.

TABLE II: SEARCH ACTIVITY STATISTICS BY SEARCH TASK

	Task 1	Task 2	Task 3	Test Statistics
Type of activity				
Total time	378.25	314.17	263.33	$F(2,9)=1.47$ $p>.05$
Fixation count in searching	76.42	44.25	21.83	$F(2,9)=8.52$ $p<.01$
Fixation count in search results	268.25	139.92	152.08	$F(2,9)=2.05$ $p>.05$
Fixation count in selected webpages	397.75	539.08	395.92	$F(2,9)=2.00$ $p>.05$
Fixation duration in searching	27.23	15.51	8.17	$F(2,9)=9.89$ $p<.01$
Fixation duration in search results	60.43	31.50	31.95	$F(2,9)=1.95$ $p>.05$
Fixation duration in selected webpages	91.02	129.57	87.31	$F(2,9)=1.18$ $p>.05$
(Meta)cognitive process				
Time in planning	50.32	27.85	40.93	$F(2,9)=18.36$ $p<.001$
Time in evaluating	151.45	161.07	119.26	$F(2,9)=0.62$ $p>.05$
Frequency of controlling	33.50	18.25	11.00	$F(2,9)=7.38$ $p<.05$

Note: All the measures of time spent or fixation duration in a certain search activity were computed in second.

Significant differences were found for two activity measures across the three tasks: eye fixation duration in searching and eye fixation count in searching. Post-hoc analyses using Tukey's test found that participants spent significantly longer time in searching for Task 1 than Task 3 and significantly more numbers of eye fixation counts in searching box for Task 1 than Task 3. For the activities that occurred in the search result and selected webpages, there were similar patterns across three tasks.

With regards to the cognitive processes involved in this online search, the participants spent significantly less time in planning for Task 2 than Task 1. There was not significant difference between Task 1 and Task 3. However, the time spent on evaluating search results and webpages and the frequency of controlling did not differ significantly across tasks, although participants were engaged in less evaluating and controlling for Task 3. The results are presented in Table II.

B. Eye-Movement Measures of Search Processes by Task

To depict the complete search process, I used two strategies: the activity pattern indicated by specific types of activities and the scanpaths which considered saccades and fixations. The activity pattern was illustrated by mapping out the type of search activity based on the order of its occurrence along the timeline during the search process. Fig 1 shows an example from subject 004. The overall patterns showed that when working on Task 1, the time was allocated to each type of search activity approximately evenly, whereas for Task 2, more time was spent in scanning the search result page and viewing selected webpages than constructing and revising search queries. The completion of Task 3 followed a somewhat similar search pattern to Task 2, with lower frequency of scanning search results and reading selected webpages.

The scanpaths were illustrated by the gazeplots produced by TOBII Pro Eye Tracker. Fig. 2 presents the gazeplots from subject 011 as an example when viewing the search result page. In her first round of search for Task 1, she followed a linear path when viewing the search results. For Task 2, she paid more attention in the search box, which implied that she dedicated more cognitive or metacognitive thinking to the search queries she constructed after viewing some of the search results. This showed her involvement in the control process during this stage of search. For Task 3, it appeared that this subject gazed more at the search results, which suggested that she was engaged in cognitive or metacognitive thinking about each search result to determine whether the search query was effective or the search result was relevant.

VI. Discussion and Conclusion

This study was designed to examine online search processes using authentic search tasks in an unconstrained setting. Three search tasks were designed in such a way that they differed from each other in different facets, including the complexity level and the nature of the task. The purpose of the study was to examine whether search processes (both by activity and by cognitive processes) differ according to the types of search tasks.

Contrary to previous studies [14], [19], the current findings did not find significant differences in time in task completion by task type. Suppose relatively easier tasks usually takes less time to complete, however, the current samples spent least time in the argument-based task (Task 3), and the less complex task (Task 1) took the longest period of time. One possible reason was the order of the presentations of the three tasks. Task 1, although relatively easier, was presented first. Participants were more likely to take it as the opportunity to get familiar with the experiment procedure and process. When it comes to the last task (Task 3), they became more certain and clear about the procedure and might be more confident about completing the tasks.

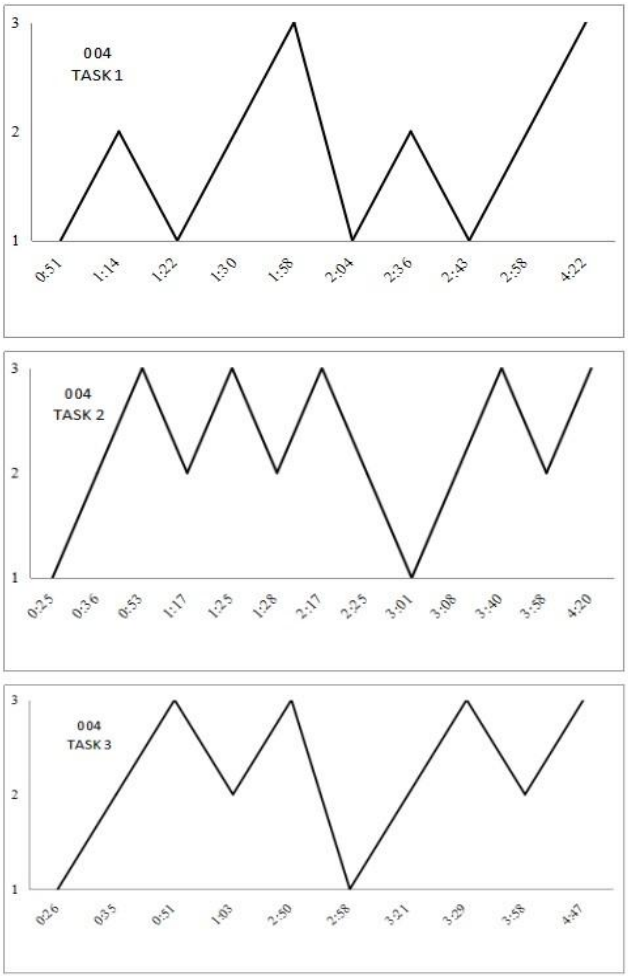

Fig. 1. Search process plot by types of tasks. 1 = Construct and revise search queries; 2 = Scan search results; 3 = Access a selected webpage

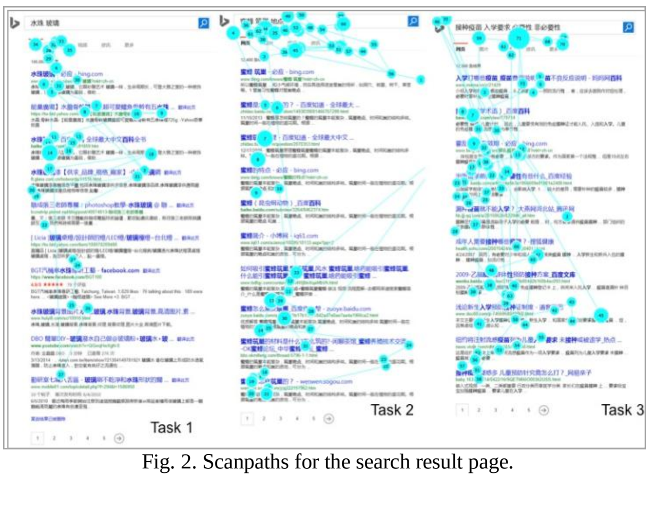

Fig. 2. Scanpaths for the search result page.

Similar reasons can be applied to the findings that participants spent significantly more time in searching for Task 1 than Task 3 and significantly more numbers of eye fixation counts in searching box for Task 1 than Task 3. Although the results failed to achieve the significance level, participants particularly read selected webpages for longer time with a higher eye fixation frequency for Task 2. This reflected a higher cognitive demand for tasks that were more complex.

In terms of the cognitive processes involved in online search, participants spent significantly less time in planning for Task 2 than Task 1. This could be interpreted as a higher level of readiness or confidence when participants worked on the second task. Despite no other significant differences across the tasks, it is noteworthy that participants did not engaged in as much in evaluating and controlling for argument-based tasks (Task 3) as the other two tasks. It appeared that when constructing an argument, participants tended to rely more on their independent thinking than simply looking for information on the Internet for information (fact)-based problems. This clearly warrants further investigation.

The activity patterns and scanpaths evidenced further that participants completed the three tasks in different manners. A scrutiny of all the patterns and paths for all the participants, it revealed that they adopted different strategies to solve each assigned task.

There are some limitations to this study. First, although a sample of 12 participants was not unusual for eye-tracking studies given the complexity and cost of data collection [10], the extremely limited sample size caused more challenges when we sought for significant group differences. Possibly, with a larger sample group, the group differences could have achieved the level of significance. Second, the reasons behind observed differences across tasks calls for further studies. Other types of data such as interview or think-alouds could supplement eye-tracking data to shed further light on the findings. Last, more advanced techniques are needed to analyze the activity patterns and scanpaths accumulatively, rather than assessing individual patterns or paths.

In conclusion, the current research confirmed again that individuals seek information online with different purposes and requirements in different ways. Furthermore, a major merit of this study is the analyses of eye-tracking data by varying levels: search activity, cognitive process and search patterns. Future studies can attempt to collect more data with a more diverse sample and a wider range of different tasks in a naturalistic setting, which will help improve our understanding of how search task types affect search process. This would allow us to manipulate the types of search tasks to provide corresponding training and exercise to improve online search efficiency.

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