Connecting Qualitative and Quantitative Analysis of Web Search Process: Analysis Using Search Units

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Abstract. Our final goal is to understand exploratory searches as four levels of search processes: search task, intent unit, search unit, and link unit. To complete these objectives, we used qualitative data to categorize participants' information needs for search units and quantitatively analyzed whether differences in the information needs of search units influence users' search processes and how task types and groups affect search units. In the experiment, eleven undergraduates and five graduates conducted information gathering task for writing a report and trip planning. We recorded their verbal protocols during the tasks and post interviews, browser logs, screen captured video, and eye-tracking data. We divided the process of exploratory searches into search units. Then search units were classified into the two types of information needs, navigational and informational, based on qualitative data. We conducted a quantitative analysis to compare between tasks and groups and types of search units. The results showed that there were many differences between the information and navigation search units.

Keywords: Exploratory search, search intent, information seeking behavior.

1 Introduction

Web searches are a part of various daily activities. For instance, people engage in information searches to help them make decisions, learn new things, and conduct

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investigations on many different topics. Bates [1] created the berrypicking model to describe searching behavior in online and information systems and suggested that researchers should focus on the sequence of search behaviors. Marchionini [2] referred to three kinds of search activity: lookup, learning, and investigation and defined an "exploratory search" as one associated with learning and investigation activities. There were a series of studies examining the influence of task types and user attributes on information seeking behaviors in exploratory searches by analyzing various data from client-side search logs, think-aloud protocols, eye-tracking, and post-experiment interviews [3][4][5]. Our approach is to extend them and to establish a situation for exploratory searches in the laboratory where we can observe participants' behaviors.

White and Roth [6] said that people engaged in exploratory searches are generally: (1) unfamiliar with the domain of their goal; (2) unsure about the ways to achieve their goals; and/or even (3) unsure about their goals. The search tasks of our experiments were open-ended (i.e., to collect information for writing a report about world history) and participants had to decide what they would focus on. The aim to correct information for the tasks was shared by the participants, but more their detailed information needs were varied. Participants in our experiments were unfamiliar with their goal or unsure about how to achieve them, and consequently, their searches were exploratory.

Our previous analysis did not examine whether their detailed information needs changed during the search process Moreover, we have analyzed qualitative data and quantitative data separately. Bridging these gaps between qualitative and quantitative is not just problem for us, but for the whole research community investigating information seeking behavior and IR.

In this study, we used qualitative data to categorize participants' detailed information needs during their searches and quantitatively analyzed the categorization results. We used the taxonomy of web searches proposed by Broader [7] to categorize information needs. Our purpose is to reveal how different information needs affected the participants' search processes. Below, we briefly discuss related work and our framework to analyze exploratory search processes.

2 Related Work

Researchers analyzing query logs have often collected transaction logs from search engines. Such studies have used the "session" as a unit of search processes [8]. These studies on query logs in search engines used the interval time from the search engine as criteria to cut a session [9][10].

On the other hand, analyses of client-side logs rely on users' interaction data with Web browsers. These studies have to extract behaviors related to searches. White and Drucker [11] defined a search trail to extract search processes from client-side logs. Search trails start from a directed search and proceed to the following points of termination: return to homepage, check email or logon services, type URL or visit bookmarked pages, page timeout, and close the browser. White and Drucker extracted search trails from client-side logs of two thousand

Table 1. Four Levels of Search Processes

Levels	Definition
Search Task	The overall process to complete the search task. The concept of the search task is similar to the search trail concept of White and Drunker[11]. The range of the search trail is broader than the search task.
Intent Unit	Continuous process while searching for the same target. The concept of the intent unit is similar to that of the search mission by Guo and Agichtein[12].
Search Unit	Continuous process while searching a single query. A search unit ends when users submits new query.
Link Unit	Continuous process while linking non-search results pages. A link unit starts when the user click a link in SERP and ends when he or she returns to SERP.

volunteer users during a six month period and found two types of interaction patterns (navigators and explorers). Guo and Agichtein [12] also used client-side logs to predict changes in search intent. They defined an interaction that leads to results pages as a search and referred to a sequence of consecutive searches as a search mission. A search mission changes when a user submits new query that doesn't overlap with the previous one. They constructed a model to predict whether the user will continue on the same mission or switch to a new one. These studies are strongly associated with our interest. However, our study differs in its methodology from these studies. We used users' own thought in to extract users' information needs.

In accordance with the previous studies, we defined four levels of search processes. Table 1 shows the definition of each level. "Search task" denotes the overall process of searching. "Intent unit" is used to denote changes in the searcher's intent. "Search unit" means a search using a query. "Link unit" starts when users click a link in SERP and ends when users return to SERP.

In this study, we focus on the search unit level and categorize information needs in search units. The research questions are (1) Do differences in the information needs of search units influence users' search processes? and (2) How do task types and groups affect search units?

3 Experiment

The participants were 11 undergraduate students of various (ages: between 19 and 21; male: 5, female: 6) and 5 graduate students (ages: between 23 and 28; male: 4, female: 1). The undergraduate students' academic majors included economics, literature, electronics engineering, Spanish, psychology, chemistry, and civil engineering, and the graduate students' were in library and information science.

The participants conducted two different web searches: the report task and the trip task. In the report task, the students were required to gather information from web pages concerning a topic of world history, a requisite subject for every

high school student in Japan. In the trip task, participants were required to gather information from web pages for planning a trip. Participants selected a particular topic for each task based on their own interests, so the experimental searches were exploratory in nature: e.g., aimed at concrete tasks in the Report Task; at destination, trip partner, and traveling season in the Trip Task.

The participants answered a pre-test questionnaire about their information-seeking experiences with web search engines in their daily lives. We set up experimental equipment and calibrated an eye-tracking system. The participants were given a five-minute period to practice a web search and the "think aloud" method, in which they orally described their thought process. The two search tasks were conducted for 15 minutes. The order of the tasks was counterbalanced between participants. After each task, a questionnaire about the degree of difficulty and satisfaction with the search results was completed. Subsequently, we interviewed the participants about their information-seeking process while showing them screen captured video of their PC use with eye-movements to facilitate episodic memory retrieval.

4 Methods of Analysis

In our previous studies based on browser logs and screen capture video, we first used time markers and tags to mark page categories, action categories, and the depth of links from the search engine results, as explained below. Additionally, we divided their search processes into a number of search units according to the following rules.

- Search units changed when users submitted a query or clicked a related search in SERP.
- Search units changed when users moved a SERP that viewed other tab window or added it bookmark in previous searches by clicking a tab or selecting a bookmark.
- Search units did not change when users moved a page except SERP that viewed other tab or added it bookmark in previous searches by clicking a tab or selecting a bookmark.
- In a category search, search units changed when users selected a category first or move from a lower rank category to a higher rank category.
- In a category search, search units did not change when users moved from a higher rank category to a lower rank category.

Next, we categorized the informational needs of search units into navigational or informational based on the participants' verbal protocols during the task and post interview. Navigational needs are those to reach a particular site whereas informational needs are those to acquire information assumed to be present on one or more web pages [7].

In this analysis, we compared users' search processes between tasks, groups, search unit types. We used 5% as the level of statistical significance.

5 Results

5.1 Overview of Results on Search Units

The total number of search units was no significant differences between the two tasks and two groups. Table 2 shows the averages for the number of each type of search unit and the averages for the time of each type of search unit. A two-way ANOVA revealed significant differences between the two search unit types regarding the number of search units and the time. The number of information search units was more than the number of navigation search units . Moreover, the time of navigation search units was longer than the time of information search units .

Table 2 also shows the average number of each type of page and the averaege reading times. The pages participants read while searching were categorized into two types: SERP (Search Engine Results Pages) and nonSERP (non Search Engine Results Pages) based on the URLs.

First, we report the results for the number of pages. We conducted a four-way mixed ANOVA with page type (SERP and nonSERP) as a within participant factor and task type (Report and Trip), participants' group (graduates and undergraduates), and search unit type (information and navigation) as between-participant factors. There were significant interactions between page types and task types , and page types and search unit types . The results of Bonferroni multiple-significance-tests showed that the number of nonSERPs in the trip task was more than the number of nonSERPs in the report task . The results also show that the number of SERPs in information search units was more than the number of SERPs in navigation search units . In contrast, the number of non-SERPs in navigation search units was more than the number of nonSERP in information search units .

Next, we analyze the results of reading time. A three-way mixed ANOVA showed a significant interaction between page types and search unit types . The results of Bonferroni multiple-significance-tests showed that the reading time of SERPs in information search units was longer than the reading time of SERPs in navigation search units . In contrast, the reading time of nonSERPs in navigation search units was longer than the reading time of nonSERPs in information search units .

Table 2. Overview of Results on Search Units

	Undergraduate (n = 11)				**Graduate (n = 5)**			
	Report		**Trip**		**Report**		**Trip**	
	navi	**info**	**navi**	**info**	**navi**	**info**	**navi**	**info**
Ave. Num. of SU	1.27	6.27	1.45	5.45	4.00	5.40	2.00	5.80
Ave. Time of SU	187.02	104.94	92.71	98.35	165.63	124.22	175.22	94.10
Ave. Num. of SERP	1.57	2.77	1.13	1.95	1.40	2.41	1.50	2.10
Ave. Num. of nonSERP	7.79	3.71	10.88	8.78	9.80	7.30	14.50	7.52
Ave. Time of SERP	6.96	26.05	9.65	15.84	13.87	34.66	12.15	17.35
Ave. Time of nonSERP	84.78	70.85	164.61	77.25	172.31	69.32	151.26	105.45

Table 3. Average Number of Actions

Action	Undergraduates (n=11)				Graduates (n=5)			
	Report		Trip		Report		Trip	
	navi	info	navi	info	navi	info	navi	info
search	1.00	1.00	0.69	0.97	0.95	0.93	0.90	1.00
link	3.50	2.38	4.63	5.30	3.55	2.70	6.40	3.52
next	0.21	0.03	0.25	0.10	0.10	0.07	0.00	0.03
back	2.86	2.20	3.38	3.18	1.35	0.93	2.20	1.10
jump	0.57	0.22	0.69	0.20	0.30	0.15	0.70	0.31
browse	0.00	0.29	0.00	0.03	0.00	0.15	0.00	0.10
submit	1.00	0.00	1.13	0.25	1.65	0.19	1.70	0.21
bookmark	0.79	0.57	0.81	0.62	1.00	0.74	1.50	0.86
change	0.29	0.33	0.75	0.45	4.15	4.93	4.30	3.41
close	0.07	0.04	0.50	0.30	0.30	0.56	0.50	0.86

5.2 Results of Actions in Each Search Unit

We defined ten categories of action to analyze user behavior on the Web.

- Search: searching with a search engine
- Link: clicking on a page link
- Next: going forward to the next page
- Back: going backward to the previous page
- Jump: going forward or backward to more than one page
- Browse: going to the nth search result in SERP
- Submit: clicking a submit button
- Bookmark: adding bookmarks
- Change: changing from one tab to another
- Close: closing a tab or window

Table 3 lists the average number of actions carried out for each search unit type in each task by the graduate and undergraduate students. In those categories, we did not analyze the "search" action; the number of search actions in most units was 1, because we separated the units on the basis of the search actions. We analyzed each search unit separately, and we conducted a three-way mixed ANOVA with task type, participants' group, and search unit type as between-participant factors. There were significant differences between the two tasks for the Link actions, between the two groups for the Next , Back , and Change actions, and between the two search unit types for the Jump and Submit actions.

The participants were significantly more likely to click links during the trip task than during the report task. The undergraduates forwarded to next pages and clicked back to previous pages more often than the graduates did. The graduates switched more often to different tabs or windows compared with the undergraduates. The participants forwarded or backwarded to more than one page and clicked a submit button more often in the navigation search unit than in the information search unit.

Table 4. SERP Lookzone

Browser control area	SERP contents area
1:Title bar, 2:Menu, 3:Bookmark, 4:Tool bar, 5:URL bar, 6:Search bar, 7:Search bar button, 8:Tab, 12:Scroll bar, 21:Find in a page, 22:Status bar	9:Link for services, 10:Query box, 11:Search button, 13:Number of hits, 14:Sponsor Link, 15:Spell check, 16:Title, 17:Snippet, 18:URL, 19:Related search, 20:Link for next page

Fig. 1. Location of blocks in Lookzone

5.3 Results of Eye Gaze Points for SERP

We defined 22 Lookzone blocks on the page to classify exactly where participants were looking on the SERP (Table 4 and Figure 1). Next, we captured images from the eye tracking data of the participants at 0.5-second intervals, beginning as soon as the results pages were presented to them. We then manually tagged where the eye gaze points in the extracted images fell within the Lookzone. Table 5 shows the average number of eye gaze points per search unit carried out for each search unit type in each task by the graduate and undergraduate students. We did not analyze 11 underlined Lookzone blocks in table 4 whose average number of eye gaze points was under 0.5. As in the analysis of actions in each search unit, we conducted a three-way mixed ANOVA with task type, participants' group, and search unit type as between-participant factors.

There were significant differences between the two tasks for the Sponsor link , between the two groups for the Search bar , Link for services , and Query box , and between the two search unit types for the Query box and Title lookzone. There were significant interactions between task types and search unit types for the Snippet and URL lookzone.

Regarding the task types, the participants were significantly more likely to gaze at the Sponsor link during the trip task than during the report task. Regarding

Table 5. Average Number of Lookzones

	Lookzone	Undergraduates (n=11)				Graduates (n=5)			
		Report		Trip		Report		Trip	
		navi	info	navi	info	navi	info	navi	info
1	Title bar	0.09	0.66	0.13	0.13	0.05	0.04	0.00	0.14
3	Bookmark	0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.03
6	Search bar	0.00	0.00	0.00	0.00	0.85	0.63	0.20	0.66
8	Tab	0.36	1.38	1.67	1.12	0.80	1.63	0.10	1.00
9	Link for services	0.91	2.98	0.13	0.85	0.05	0.41	0.40	0.24
10	Query box	1.27	6.36	1.00	1.88	0.40	0.74	0.30	0.41
14	Sponsor Link	0.09	1.18	1.20	1.81	0.00	0.00	0.60	1.76
16	Title	2.91	10.78	3.80	6.37	1.55	6.56	1.20	6.48
17	Snippet	2.18	15.92	3.47	5.40	2.75	11.81	0.70	4.66
18	URL	0.45	7.36	1.93	2.17	0.45	3.07	0.70	1.90
19	Related search	0.09	0.52	0.20	0.38	0.05	0.19	0.10	0.17

the groups, the undergraduates gazed at the Query box and Link for services more often than the graduates did. In contrast, the graduates gazed at the Search bar more often than the undergraduates did. Regarding the search unit types, the participants gazed at the Query box and Title more often in the information search unit than in the navigation search unit.

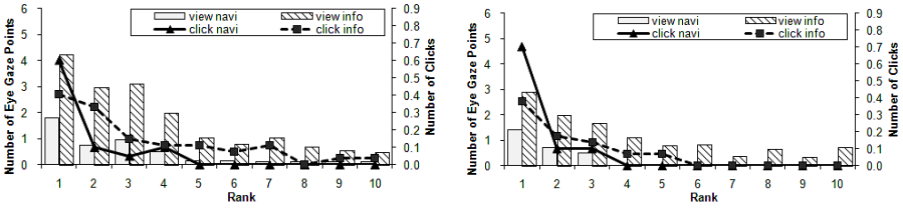
Moreover, regarding the interaction between the task types and search unit types, the participants gazed at the Snippet and URL in the information search unit more than in navigation search unit for the report task . The participants also gazed at the Snippet and URL in information search unit for the report task more than for the trip task .

5.4 Results of View Rank and Click Rank

Table 5 shows that there was a clear tendency for students to focus on the titles, URLs, and snippets of the hits displayed on the results pages. We consequently grouped the eye-gaze points on titles, URLs, and snippets and assigned rankings. Then we analyzed which rankings attracted the most views. Figure 2 and Figure 3 show the average number of eye gaze points for each search unit type in each task. Figure 2 shows the results of undergraduates and figure 3 shows the results of graduates. As in the previous analyses, we conducted a three-way mixed ANOVA with task type, participants' group, and search unit type as between-participant factors.

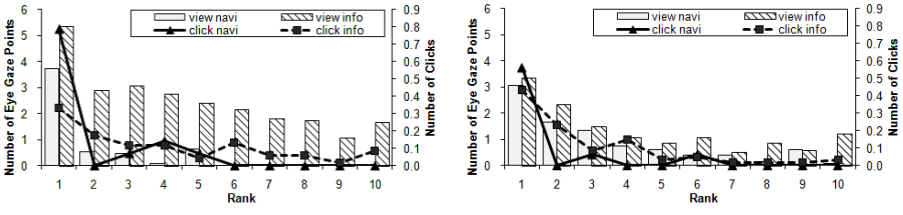
First, we analyzed the view rank. There were significant differences between the two tasks for rank 1 , between the two groups for rank 1 and rank 5 , and between the two search unit types for ranks 1-6, 8, and 10 . There were significant interactions between task types and search unit types for rank 7 .

Regarding the task types, the participants were significantly more likely to gaze at rank 1 during the report task than during the trip task. Regarding the groups, the undergraduates gazed at ranks 1 and 5 more often than the graduates did. Regarding the search unit types, the participants gazed ranks



(a) Report Task (b) Trip Task

Fig. 2. Average number of eye-gaze points and click rank (Undergraduates)



(a) Report Task (b) Trip Task

Fig. 3. Average number of eye-gaze points and click rank (Graduates)

1-10 more often in the information search unit than in the navigation search unit. Regarding the interaction between the task types and search unit types, the participants gazed at rank 7 in the information search unit more than in the navigation search unit for the report task. The participants also gazed at rank 7 in the information search unit for the report task more than for the trip task.

Next, we analyzed the click rank; there were significant differences between the two search unit types for rank 1 and rank 2. The participants clicked rank 1 more often in the navigation search unit than in the information search unit. In contrast, the participants clicked rank 2 more often in the information search unit than in the navigation search unit.

6 Discussion and Conclusion

In this study, we divided exploratory search processes into search units based on qualitative data and quantitatively analyzed the differences in each type of search unit We also investigated the relationship between the type of task or user group and the type of search unit. This section discusses the results of the analysis.

First, we summarize the characteristics of each type of search unit. The information search units viewed more SERPs as compared with the navigation search units. Moreover, the navigation search units viewed more nonSERPs as compared with the information search units. These results indicate that users thought SERPs were more important in the information search units and thought nonSERPs were more important in the navigation search units.

These differences imply the information needs in each type of search unit. The navigation search unit is to search for a navigation path to a particular site.

In many cases, the target pages in the navigation search units were displayed at a higher rank in SERP. For example, say you wanted to go to Wikipedia; you would submit a query "Wikipedia" and Wikipedia would be ranked first in SERP. Similarly, in the navigation search units, users did not have to look deeply at the SERPs; their target information was beyond it.

On the other hand, the information search unit is to search one or more pages in order to acquire the target information. Therefore, users in the information search units scanned down to the lower ranks of SERP and read snippets to evaluate whether the documents were relevant or not.

This study was our first attempt at bridging the gap between qualitative and quantitative analyses. In the future, we will use these findings to extract search units and predict information needs from client-side logs. Additionally, we will try to extract and categorize the intent unit level in a second attempt to connect qualitative and quantitative data.

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