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Kyoungsik Na Jisu Lee

Article information:

To cite this document:
Kyoungsik Na Jisu Lee , (2016),"When two heads are better than one", Aslib Journal of Information Management, Vol. 68 Iss 5 pp. 545 - 565
Permanent link to this document:
http://dx.doi.org/10.1108/AJIM-04-2015-0057

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When two heads are better than one

Query behavior, cognitive load, search time, and task type in pairs versus individuals

Kyoungsik Na
Konkuk University, Chungju, South Korea, and
Jisu Lee
RIKS at Korea University, Seoul, South Korea

Received 15 April 2015
Revised 25 May 2016
Accepted 25 May 2016

Abstract

Purpose – The purpose of this paper is to explore the differences between collaborative and individual search techniques in a scenario-based task focussed on query behavior, cognitive load, search time, and task type about the search.

Design/methodology/approach – To help understand the influences on searching for relevant information in pairs or individual contexts, the authors conducted an exploratory user study with 30 participants, using two search tasks completed in a controlled laboratory setting.

Findings – On the basis of the analysis, the authors found that collaborative search teams resulted in more queries, more diverse query terms, and more varied query results compared to those working individually. The study results indicated that the cognitive load imposed on the participants did not differ between a collaborative search and an individual search except for the component of performance on the NASA Task Load Index. The results further showed that the total search time was a significant difference on average between the two conditions (i.e. individual information search and collaborative information search) for the second task. And there were significant differences of the mean of total search time between the two tasks for the both conditions. The authors also found that there was no significant relationship between query behavior and the total cognitive load.

Originality/value – The findings from this study have implications for a better understanding of collaborative search interface design, searchers' cognitive load, query behavior, and general collaborative information search.

Keywords Collaborative search, Cognitive load, Individual search, Query behaviour, Search time, Task type

Paper type Research paper

1. Introduction

Due to the advance of information and communication technology (ICT), information searching on the web has become a daily routine behavior for many people (Purcell, 2011), and has made further collaboration easier in many work contexts, such as academic, industry, medicine, or military settings (Foster, 2006). During the last decade, the field of collaborative information seeking has been introduced and there is a growing interest and an associated body of research examining the need and desire for collaboration in information seeking, searching, and retrieval (Foster, 2006; Poltrock *et al.*, 2003; Yue *et al.*, 2013; Shah, 2010a, 2013; Shah and González-Ibáñez, 2011; González-Ibáñez *et al.*, 2013). According to Poltrock *et al.* (2003), collaborative information seeking is "the activities that a group or team of people undertakes to identify and resolve a shared information need" (p. 239). Shah (2010b) similarly stated

This work was supported by the faculty research fund of Konkuk University in 2013.

Aslib Journal of Information Management
Vol. 68 No. 5, 2016
pp. 545-565
© Emerald Group Publishing Limited
2050-3806
DOI 10.1108/AJIM-04-2015-0057

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that "collaborative information seeking is a group of participants intentionally working together in an interactive manner for a common goal" (p. 26). Foster (2006) continues by defining collaborative information seeking as "systems and practices that would enable individuals to collaborate during the seeking, searching, and retrieval of information" (p. 330). Thus, both early and recent research into collaborative information seeking highlighted the interaction between the system and humans as being aimed at resolving a common information need by working together.

In recent years, studies have supported and, thus, developed collaborative information search (CIS) interfaces, such as Ariadne (Twidale *et al.*, 1997), SearchTogether (Morris and Horvitz, 2007), Cerchiamo (Golovchinsky *et al.*, 2008), Coagmento (Shah, 2010c), and CollabSearch (Yue *et al.*, 2012). Hearst (2009) stated that "designers of Web search interfaces have learned that in order to be able to successfully serve their highly diverse user base, they must be very careful about any complexity that they introduce" (p. 2). However, the search interface has been mainly developed to support an individual, rather than a collaborative, search. As information searching becomes increasingly ubiquitous, there arises a need to identify ways to examine the performance and effects of CIS.

Recently, different aspects of cognitive load have been studied in relation to information science, including mental effort (Gwizdka, 2009), cognitive load distribution (Gwizdka, 2010), query reformulation behavior (Na, 2012), and information visualization (Huang *et al.*, 2009), yet few studies have investigated the ways in which cognitive load affects a searcher's query behavior as a function of task difficulty and performance. Investigations of the effects of cognitive load on query behavior are motivated by both basic and applied concerns. Understanding the effects of cognitive load on query behavior can help develop and refine CIS engines and, more generally, human information processing.

In this study, we explored the query processes and strategies of searchers across search task stages and sought to improve our understanding of elements affecting cognitive load and search time in a collaborative search context. Our aim was to further explore the relationships among searchers' query behavior, search time, and cognitive load induced by the participants searching for relevant information in collaborative vs individual conditions. While there is a wealth of literature on individual information search (IIS), including how it relates to precision, relevance, user performance, or search engine retrieval performance, little research has been done on CIS in relation to the impacts of cognitive load on query behavior and search time. The findings from this study will have implications for search engine use, search engine interface design, users' cognitive load, and, more generally, the CIS process.

2. Related studies

In the following section, we will review recent research in the areas of CIS, query behavior, and cognitive load.

2.1 Collaborative search

Past information retrieval (IR) research has been focussed on an individual, rather than a collaborative, search context. However, during the last decade, several studies on collaborative searching have been conducted in various settings. Collaboration in learning often occurs in educational environments (Brindley *et al.*, 2009) as well as in organizational settings (Morris, 2007). Recent studies have revealed that people often collaborate when they are searching for relevant information on the web, and,

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compared to individual searches these collaborative searches were found to be more effective for query formulation and results examination (Capra *et al.*, 2013), to produce a more diverse searching vocabulary and reduce redundant documents (Joho *et al.*, 2008), and to allow for the discovery of more and diverse information overall (Shah and González-Ibáñez, 2011; Yue *et al.*, 2013). Foley (2008) revealed that an appropriate division of labor and mediated maintenance for sharing information need and knowledge are necessary to enhance CIS performance. Pickens *et al.* (2008) assessed the effectiveness of algorithmic mediation in a collaborative search context vs an individual one. They found that CIS revealed more relevant documents than those found in an individual setting. Shah *et al.* (2010) also applied algorithmic mediation to the CIS process among small groups of searchers with a shared information need. They found that CIS performed more effective searching process throughout the session than IIS did. In addition, CIS teams discovered more unique relevant information relates to their topics than individual searchers did.

Capra *et al.* (2013) examined searcher actions and strategies in asynchronous CIS using a laboratory study with a think-aloud protocol. On the basis of their analysis of the think-aloud data and screen recordings, they showed that collaborators' prior work influenced search strategies and behaviors, and that the participants leveraged collaborators' work at various stages of the interaction, including query formulation and results examination. Shah and González-Ibáñez (2011) examined the synergic effect of CIS, showing that remotely located searchers were able to formulate a wider range of queries than were those pairs that were collocated or artificially created. They further found that collaborators working remotely were able to achieve synergy while still being able to think and work independently. Joho *et al.* (2008) compared CIS and IIS using a recall-oriented task, and showed that the collaborative conditions helped to diversify search vocabulary while reducing the bookmarking of redundant documents within teams. González-Ibáñez (2012) also contributed to a better understanding of the role of positive and negative effects in the information search process of collaborative teams. In addition, Yue *et al.* (2013) examined users' query behavior from three aspects: comprising the number of queries, query reformulation patterns (i.e. new, specification, generalization, and reconstruction), and query performance. Their findings revealed that queries are more diverse in a collaborative search and that recall-oriented tasks and searchers employed new and specialized patterns more often as query reformulation types in CIS, while individual searchers used a reconstruction pattern more often. Further, the successful query rate was higher for IIS and recall-oriented tasks.

Some studies have been designed to compare information web searches for individuals or pairs, and several user studies on collaborative searches have been conducted to compare information web search. These studies have demonstrated that team members or people work together when performing searches to solve complex problems (Twidale *et al.*, 1997; Evans and Chi, 2008; Morris, 2008; Shah and González-Ibáñez, 2010; Yue *et al.*, 2014). These studies have investigated several dimensions of collaborative search, such as search tasks and strategies in collaboration (Morris, 2008; Shah and González-Ibáñez, 2010; Yue *et al.*, 2014), search effectiveness in collaborative search tasks (Shah, 2013), and collaborative searches on a recall-oriented task (Joho *et al.*, 2008). Early studies provided basic information about the effectiveness and advantages of CIS. From the literature, it can be seen that CIS might have the potential to be more synergic than IIS. In addition, collaborative web searches involve more complex search processes. In relation to this, Shah and González-Ibáñez (2011) stated that a synergic effect in CIS is one of the core values and advantages of this technique.

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With our study, we contribute to the analysis of the differences between collaborative and individual search techniques in a scenario-based task focussed on query behavior, cognitive load and search time differentiated by the search task type. In particular, we compared individuals and distributed collaborative searches on the web to explore user behavior in a natural setting.

2.2 Cognitive load

Cognitive load has been rigorously studied in educational settings and ergonomics in industry in terms of reducing improper cognitive load imposed on human for better performance. However, there are few studies in the IR field on cognitive load, even though it has gained growing attention in the context of library and information science.

For cognitive processing of information, we make use of working and long-term types of memory (Baddeley, 1992). In humans, working memory is used to process new information but its capacity is limited, so it is important that system designers consider this when developing IR systems. On the other hand, long-term memory is used to store information from the working memory and to retrieve stored information when needed later. It is considered that not overloading the working memory capacity may yield a good chance of transferring information into long-term memory. Cognitive load theory proposes that there are three types of cognitive load (i.e. intrinsic, extraneous, and germane) and these are additive (Sweller, 1988). Thus, the total sum of these three types of cognitive load should be less than working memory capacity in order to promote effective information processing. In educational settings, to maximize the transferal of learned information from working memory to long-term memory, it is recommended that information be presented in a way that reduces extraneous cognitive load and simultaneously increases germane cognitive load, if possible.

A search task itself might possess intrinsic cognitive load because there are levels of complexity inherent in the task being processed. Further, there are potentially different levels of complexity for intrinsic cognitive load in that some tasks are more complicated than others. However, CIS might increase the chance of a germane cognitive load when members in a team assist each other by sharing information that is to be processed. Gwizdka (2009) assessed the cognitive load associated with Web search tasks in a controlled study with 48 participants. He examined cognitive load from the perspective of dual-task performance, and the primary task performance components were found to be significantly related to both objective and subjective task difficulty. However, the relationship between objective and subjective task difficulty and the secondary task performance measures was weaker than expected. Gwizdka (2010) further examined the distribution of cognitive load in the web search task using a new variant of the dual-task method, and found that average cognitive load varied by search task stages and that cognitive load was significantly higher during query formulation and user description of a relevant document, as compared to during the examination of search results and viewing of individual documents. Na (2012) examined the effect of cognitive load on query reformulation behavior, and indicated that those exposed to cognitive load manipulations, namely, mental demand, temporal demand, and frustration, made half as many queries as searchers not exposed to these manipulations. Furthermore, the NASA Task Load Index (NASA-TLX) cognitive load scores of searchers who were exposed to the three cognitive load manipulations were higher than those of searchers who were not exposed to these manipulations. Brennan *et al.* (2014) examined the effect of cognitive abilities on information search for tasks of varying levels of complexity, and found the following three important trends: associative

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memory ability had no significant effect on search behavior and workload, visualization ability had a significant effect on search behavior, but not on workload, and perceptual speed had a significant effect on search behavior and workload. Specifically, participants with high perceptual speed ability engaged in more search activity in less time and perceived less workload.

People experience cognitive load when they collaborate or interact with a system. The increasing complexity of the search environment might increase searchers' cognitive load. Therefore, we should consider ways to attain optimum performance in collaborative web searches under the conditions of cognitive load. In the area of collaborative information seeking, some researcher explored the cognitive load of collaborative working in a search task differs from a single user working in the same task. Yue and He (2010) also showed that the cognitive load imposed on searchers in a CIS context comes not only from the adaption to and familiarity with the system, but also from gathering information from other collaborators through their interaction and communication. González-Ibáñez *et al.* (2011) and Shah and González-Ibáñez (2011), investigated whether collaboration had negative implications for users in terms of cognitive load during their search task using NASA's TLX instrument. Through these studies, the authors found that the users' cognitive load in a real collaborative setting was not higher than what was perceived by those working individually. In summary, this line of research has illustrated that the cognitive load can be an important factor for effective collaborative web searches. In collaborative information seeking, Yue and He (2009) pointed out that there are some sources of additional cognitive load, including contributing to each other, keeping aware of what the other team member is doing, and paying attention to both the search histories of groups and individuals. However, there has been little research into this approach for drawing inferences from the association between query behavior and cognitive load. Therefore, we will need to pay attention to the extra collaborative cognitive load compared to individual web search in this study.

3. Research questions and hypotheses

As prior research in library and information science and psychology found effects of query pattern and cognitive load on performance and satisfaction, we sought to determine if there were differences on query behavior, cognitive load, and search time induced by CIS vs IIS for college students' information seeking behavior. Because task difficulty could also play a role in relation to search time, we included it in our analysis. Specifically, we address the following research questions and hypotheses:

(1) To understand differences in query behavior in the context of CIS vs IIS. To do this, we looked closely at the number of queries, query vocabulary richness (QVR), and query results similarity (QRS) (Yue *et al.*, 2013) in query behavior that was particularly affected by the CIS strategies. We hypothesized that:

H1. The CIS participants would generate fewer queries (Yue *et al.*, 2013), more diverse QVR, and fewer query results than those in the IIS condition (Joho *et al.*, 2008; Shah and González-Ibáñez, 2011).

(2) To understand the differences in cognitive load induced by CIS vs IIS. Collaboration in information seeking could not only divide some degree of labor that may reduce cognitive load but also induce some extra collaboration load

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such as interaction that may increase cognitive load and impede information search process. We hypothesized that:

H2. The CIS participants would experience less cognitive load compared to IIS participants, due to their collaboration throughout the course of a search.

(3) To assess whether total search time varies (i.e. within 30 mins, for each task) between CIS and IIS conditions. To do this, we looked further at the search condition (i.e. fact-finding search task vs exploratory search task) to see whether or not search time varies between CIS vs IIS depending upon the search condition because time and task difficulty could be significant predictors of satisfaction with search strategy (Crescenzi *et al.*, 2013). We hypothesized that:

H3. CIS participants would require less time to complete a search than IIS participants.

(4) To examine the relationships among the elements of query behavior (i.e. query propensity (QP), QVR, and query result similarity) and cognitive load. We hypothesized that:

H4. CIS participants would experience less cognitive load than IIS participants, which, in turn, would affect query behavior, such as QP, QVR, and QRS.

Thus, the specific research questions addressed in this paper were as follows:

RQ1. How does the query behavior engaged in collaborative teams working in a search task differ from the query behavior of a single user working in the same task?: (a) is there any difference in terms of the number of queries?; (b) is there any difference in terms of QVR?; (c) is there any difference in terms of QRS?

RQ2. How does the total sum of cognitive load engaged in CIS differ from that of searching information in individual setting?: are there any differences in terms of mental demand, physical demand, temporal demand, performance, effort, or frustration?

RQ3. To what extent, if any, does the total search time of collaborative teams working in a search task differs from the total search time of a single user working in the same task?

RQ4. How do the elements (e.g. the number of queries, QVR and query result similarity) of query behavior relate cognitive load between CIS and IIS conditions?

4. Methodology

4.1 Participants

Participants ($n = 30$) were undergraduate students in the library and information science program in South Korea. Our participants were frequent searchers with advanced computer knowledge. We intentionally focussed on this group since our motivation for this study was based on future information professionals rather than casual searchers. Different groups of people could be part of our future study to compare differences and similarities in variables. Among these, ten participants were randomly assigned to the IIS condition and 20 participants (ten pairs) to the CIS condition. In the CIS settings, two participants searched together in the same space but used remotely located computers and communicated with their assigned group member using a chat program facilitated by Coagmento program (Shah and González-Ibáñez, 2010). Due to the limited search time and space of the laboratory in this study, we focussed on pairs synchronous as a collaboration search team configuration. Having more than two participants in a team asynchronous in the experiments might yield interesting results such as influences on productivity, efficiency, effectiveness, and uniqueness of CIS (González-Ibáñez *et al.*, 2013) (Figure 1).

4.2 Experimental design and procedure

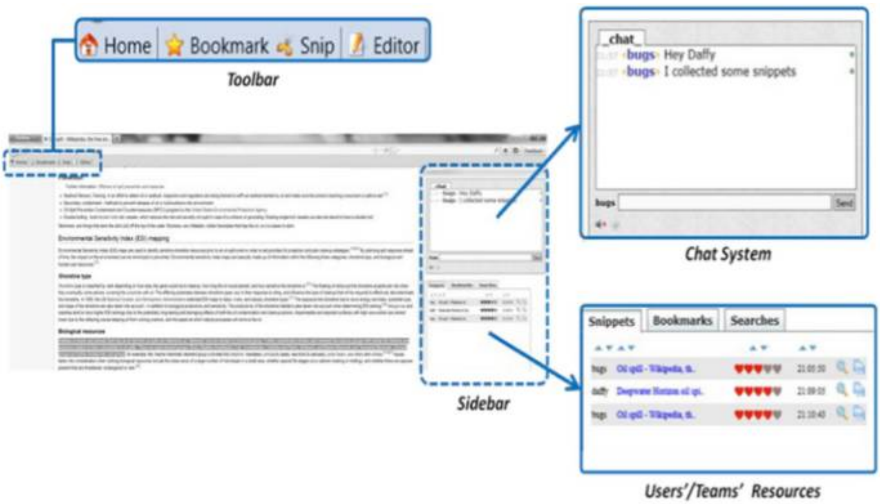
To answer the research questions discussed above, we employed an exploratory user study, including a pre-task questionnaire, experiments, and a post-task questionnaire in that order. The pre-task questionnaire assessed the participants' demographic information and previous search and group experiences. The experiments included two task-based searches for both groups. Lastly, the post-task questionnaire collected participants' cognitive load score using the modified NASA-TLX assessment tool, developed by Hart and Staveland (1988).

The participants could finish their searching at any time within 30 minutes if they were satisfied with their search results of the tasks. Based on our pilot tests, the total search time did not exceed more than 30 minutes. Therefore, we decided not to give time pressure to our participants because prior research (Crescenzi *et al.*, 2013) indicated the 15-minute search group reported the task as being more stressful, and they were less satisfied with their search outcomes. The NASA-TLX was used to measure the mental, physical, temporal, performance, effort, and frustration demands imposed on CIS and IIS participants by the search tasks. This scale uses ratings on a ten-point scale to indicate participants' perceptions from low to high. We expect that the larger the scale (e.g. ten-point Likert scale) will provide the following benefits:

(1) it offers more variance than a smaller Likert scale;

(2) it offers a higher degree of measurement precision; and

(3) it offers a better opportunity detect changes and more power to explain a point of view (Wittink and Bayer, 2003).



Source: González-Ibáñez *et al*. (2012, p. 3)

Figure 1. Coagmento program

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In summary, each experimental session lasted less than 30 min and the procedure was as follows:

(1) participants were introduced to the study and signed the consent form;

(2) participants completed a pre-task questionnaire to collect information about their previous search experience;

(3) participants completed an introductory session to become familiar with the search system (Coagmento);

(4) participants performed the first search task (within 30 mins);

(5) participants completed a post-task questionnaire to collect their NASA-TLX score and search query performance rating;

(6) participants took a 10-min break to avoid mental fatigue before the second search task;

(7) participants performed the second search task (within 30 mins); and

(8) participants completed a post-task questionnaire to collect their NASA-TLX score.

4.3 Search tasks

The simulated scenario-based search tasks from Borlund (2000) were used in this study. The scenario-based task is useful for IR studies because it may produce more expectable information needs and more natural requests for data from the users of interactive IR systems (Ingwersen and Järvelin, 2005; Kim, 2012). Therefore, the tasks in this study encourage the logical observation of searchers' task-solving behavior in experimental settings, and permit comparison between different searchers' work on the same task.

In this study, two search tasks with varying complexity levels were designed. Task 1 is a factual search task used to find leisure information about the name and price of admission to the museum focussed on the assassination and legacy of President John F. Kennedy, in Dallas, Texas. Task 2 is an exploratory search task used to find information about the side effects of mobile phone radiation on the health of children, pregnant women, and elders (see Table I). One search task (i.e. Task 1) was a more well-structured problem-solving information search task with a lower level of complexity than the other (i.e. Task 2).

All search task processes were recorded using Camtasia screen capture software while the participants performed the tasks. The participants in both conditions performed both search tasks. The experimental procedure in both conditions remained the same, except that there was only one participant in the IIS condition and two participants in the CIS condition. To minimize order effects, the order of the two tasks was counterbalanced within groups.

5. Data analysis and discussion

5.1 Query behavior

The first research question looked at three categories of query behavior during the task-based information search. To begin analysis of the query behavior, we first defined the following five types of searching behavior and looked at the statistics of searching behavior for each of the search conditions (IIS and CIS): query terms, dwell time, bookmark, total webpages, and coverage. Table II summarizes all of the measurements based on the query log obtained from this study.

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Search tasks	Questions
Task 1	In this summer vacation, you and your friend plan to visit Dallas in Texas. You want to search for information about how you will enjoy your vacation in Dallas and one of your friends who have been there suggests that you visit the museum that is known as the memorial hall to chronicle the assassination and legacy of President John F. Kennedy. You want to know the name and admission price of the museum. As you find useful information, you may want to save the relevant websites and files as bookmarks. You can save and collect as many relevant websites and files as possible
Task 2	You and your classmate have a term paper in the course of health communication. The paper will be a team research paper dealing with an area of interest related to the side effects of mobile phone radiation on human health to children, pregnant women, and elders. Your team's goal is to collect relevant information for preparing a paper on this topic. To prepare this paper, search and visit any website that you want and look for relevant information on the topic. As you find useful information, you may want to save the relevant websites as bookmarks. You can save and collect as many relevant websites and files as possible

Table I.
Search tasks

	Search condition			
	Task 1		Task 2	
	Ind.	Coll.	Ind.	Coll.
Type	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Query terms: total number of query terms	7.00 (4.62)	4.55 (2.33)	12.7 (4.88)	9.70 (5.74)
Dwell time: webpage which greater than or equal to 30 seconds	2.60 (1.43)	2.60 (1.27)	4.90 (2.08)	4.75 (1.86)
Bookmark: total number of documents bookmarked	2.60 (0.84)	6.30 (2.41)	6.00 (2.05)	10.60 (4.84)
Total webpages: total number of webpages visited	7.40 (5.17)	7.60 (3.03)	17.0 (5.10)	14.5 (4.06)
Coverage: total number of distinct webpages visited	2.7 (1.06)	2.80 (1.28)	7.40 (3.27)	4.80 (3.37)

Table II.
Statistics of searching behavior

The three categories of query behavior studied in this paper are QP, QVR, and QRS, as articulated by Yue *et al.* (2013). QP is defined as the total number of queries made by participants during the whole search task session. QVR is defined as the ratio of the number of unique query terms divided by the number of queries. QRS means "the aggregated result set retrieved in response to all the queries issued by one of the users on a team and denotes the aggregated result set retrieved in response to all the queries issued by the other user on the same team" (p. 4). In order to measure the estimations of QP, QVR, and QRS, we compared query results between the two members in a CIS team and between two random IIS searchers.

Using analysis of variance (ANOVA), we compared the query behavior of teams in each conditions based on the measures summarized in Table III. In short, the CIS participants issued more queries, had diverse vocabularies, and had more similarity than IIS participants. Detailed information about the three categories of query behavior will be introduced in the following section.

5.1.1 QB. The ANOVA results showed a significant difference in terms of the total number of queries between the two conditions for Task 1 ($F = -10.547$, $p = 0.004$) and Task 2 ($F = 11.929$, $p = 0.003$). As defined earlier, QP is calculated as the total number of queries made by participants during the whole search task session. As can be seen

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Table III.
Results taken from search logs

	Task 1				Task 2			
	Mean	SD	*F*	*p*	Mean	SD	*F*	*p*
Query propensity								
Individual	10.50	3.342	10.547	*0.004**	16.70	6.533	11.929	*0.003**
Collaboration	5.70	3.268			8.90	2.885		
Query vocabulary richness								
Individual	1.79	0.779	13.562	*0.002**	0.91	0.078	3.844	0.066
Collaboration	0.86	0.183			0.81	0.152		
Query results similarity								
Individual	0.40	0.197	0.322	0.577	0.17	0.099	8.129	*0.011**
Collaboration	0.44	0.199			0.29	0.096		

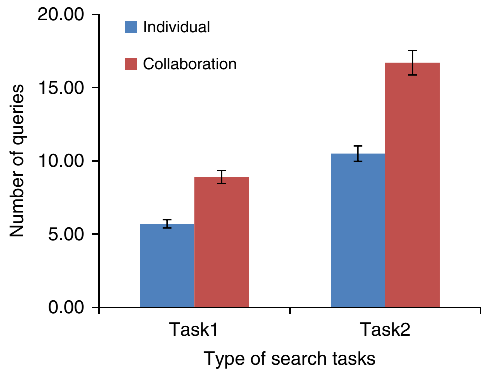
Note: $*p < 0.05$

in Figure 2, when it comes to QP, the participants in the CIS condition issued more queries than those in the IIS condition because two participants in a team can issue more queries than one individual with a given search time, even though the pair might be able to avoid redundant queries during their exploration through communication.

This could imply that the CIS teams can enhance social search interactions between the team members so that they could communicate freely and possibly have confidence in judgments when finishing the tasks. Yue *et al.* (2014) described that collaborative search could play a role in communication that affected subjects' query reformulation generating new terms for common information goals in collaborative web search, and showed that the task type could also play a role.

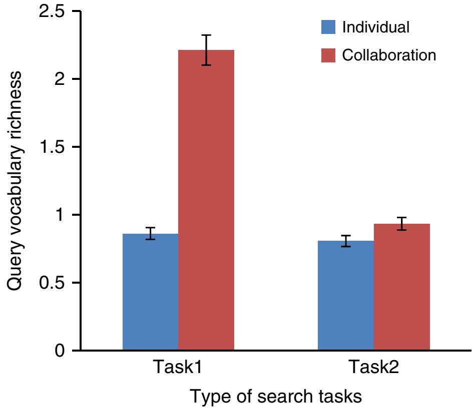
5.1.2 QVR. The ANOVA results showed a significant difference in terms of QVR between the two conditions for Task 1 ($F = 13.562$, $p = 0.002$). As defined earlier, QVR is calculated as the ratio of the number of unique query terms divided by the number of queries (Yue *et al.*, 2013).

As can be seen in Figure 3, CIS participants issued more diverse query terms than those in the IIS condition. Thus, the CIS participants constructed a higher stage of QVR than IIS participants did.



Note: Error bars represent SE

Figure 2.
Query propensity

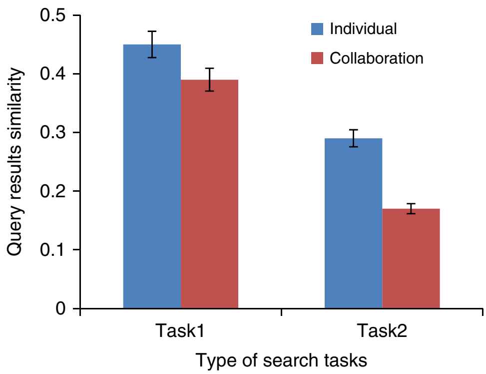


Note: Error bars represent SE

Figure 3. Query vocabulary richness

This could be one indication that CIS teams might have a higher chance of avoiding redundant search query terms and thus develop more diverse or unique query terms by communicating with each team member through the collaborative process. In the work of Tao and Tombros (2014), they also found that collaborators share or track the task process and their status by communicating with each other during solving common search task. It may help to interact with each other and to avoid overlap query terms or research results. In particular, supporting for structure construction and visualization and group awareness of the collaborative process are able to aid more effective search process among collaborators.

5.1.3 QRS. For QRS, the ANOVA results indicated that there was a significant difference between CIS and IIS with regard to QRS for Task 2 ($F = 8.129$, $p = 0.011$). According to Yue *et al.* (2013), QRS is calculated as $|\psi(\rho_1) \cap \psi(\rho_2)| / |\psi(\rho_1) \cup \psi(\rho_2)|$, where $\psi(\rho_1)$ denotes the aggregated result set retrieved in response to all the queries issued by one of the users on a team and $\psi(\rho_2)$ denotes the aggregated result set retrieved in response to all the queries issued by the other user on the same team (Figure 4).



Note: Error bars represent SE

Figure 4. Query results similarity

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To extend our investigation for query behavior on different task types, we looked at the differences of task complexity and query behavior engaged between CIS and IIS conditions on each task (see Table IV). Gwizdka and Spence (2006) found that task complexity is related to the searcher's behavior, such as the number of webpages visited, dwell time on a page, deviation from the optimal path, and the linearity of the navigation path. The results of the ANOVA test showed that there were significant effects of the different tasks between IIS ($F = 10.547$, $p = 0.004$) and CIS ($F = 11.929$, $p = 0.003$) search conditions on QP. For query result similarity, the results of the ANOVA test showed that there were significant effects of the different tasks between IIS ($F = 4.650$, $p = 0.045$) and CIS ($F = 10.352$, $p = 0.005$) search conditions. There was a significant effect on task in CIS search condition on QVR ($F = 21.459$, $p = 0.000$). The QVR is higher in Task 1 than in Task 2, which might indicate that CIS participants in Task 1 issued more diverse query terms than those in Task 2. This could be one indication that CIS teams in Task 1 might have a higher chance of avoiding redundant search query terms and thus develop more diverse or unique query terms during their search task. A higher vocabulary is not necessary in the fact-finding task because the goal was to find simple results, rather than explanatory searching as in Task 2.

5.2 Cognitive load and type of cognitive load measure

For the second research question, we looked at the total NASA-TLX cognitive load assessment score for participants' perception of the search tasks. Subjective assessments of cognitive load on the search tasks were captured by a ten-point Likert scale of agreement with each element.

The total score for cognitive load, which was adopted from Na's (2012) work, was calculated by the following equation:

$$\text{Total score of cognitive load} = \text{Mental demand} + \text{physical demand} + \text{temporal demand} + \text{performance} + \text{effort} + \text{frustration}$$

For both search tasks, the ANOVA results show that there were no significant differences between the two conditions in terms of the total score of cognitive load. The CIS participants' total score was $M = 31.60$, $SD = 6.125$, while the IIS participants' total score was $M = 29.93$, $SD = 9.548$ for Task 1. Further, the CIS participants' total

Table IV. Mean of search conditions on search tasks

	Individual				Collaboration			
	Mean	SD	*F*	*p*	Mean	SD	*F*	*p*
Query propensity								
Task 1	5.70	3.27	10.547	*0.004**	8.90	2.89	11.929	*0.003**
Task 2	10.50	3.34			16.70	6.53		
Query vocabulary richness								
Task 1	0.861	0.183	0.533	0.475	1.79	0.843	21.459	*0.000**
Task 2	0.806	0.152			0.912	0.111		
Query results similarity								
Task 1	0.447	0.203	4.650	*0.045**	0.396	0.199	10.352	*0.005**
Task 2	0.294	0.096			0.170	0.099		

Note: $*p < 0.05$

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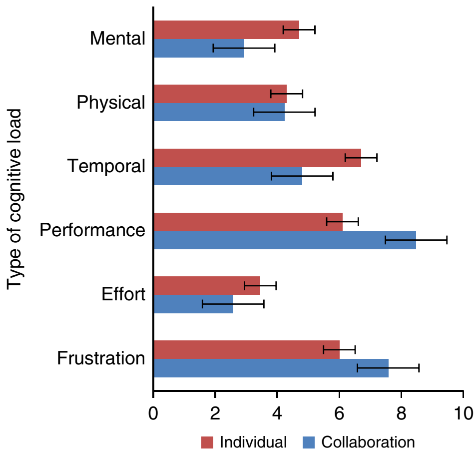
score was $M = 38.00$, SD = 4.606, while the IIS participants' total score was $M = 36.40$, SD = 4.606 for Task 2.

Task 2 was considered to be more complex and difficult than Task 1.Gwizdka (2009) stated that "although task difficulty is an issue […] it is possible that by employing tasks with a wider range of difficulty levels one could more easily observe differences in the average cognitive load at the task level" (p. 26).

Even though there were no significant differences between the two conditions, the mean value of summed cognitive load of the CIS participants was slightly higher than that of IIS participants for both tasks. This may be because the cognitive load perceived by CIS searchers might be dependent upon the burden of communication, unfamiliarity with the search system, and relevance feedback over the course of a search task. According to Yue and He (2010):

> During the whole process, the cognitive load of collaborators is not only reflected as adaption to the system, including searching tools and collaborative tools, but also reflected as getting familiar with other collaborators, including gaining trust and making contribution to each other (p. 9).

An ANOVA was conducted to assess whether there were differences between the two conditions of each component of the NASA-TLX. Among the six components (i.e. mental demand, physical demand, temporal demand, performance, effort, and frustration), the ANOVA results indicated that participants did rate the factors of temporal demand ($F = 6.773$, $p = 0.015$), performance ($F = 9.874$, $p = 0.004$), and frustration ($F = 4.302$, $p = 0.047$) differently for the Task 1 between the two conditions. Further, among the six components, participants rated the factor of frustration ($F = 6.093$, $p = 0.020$) differently for Task 2. As can be seen in Figure 5 below, the average scores for perceived performance and frustration (red bar) showed that CIS teams performed better than IIS participants. Further, perceived temporal demand (blue bar) results showed that IIS participants performed better than CIS teams for Task 1. For Task 1, CIS teams scored $M = 8.48$ (SD = 1.272) for performance, and $M = 7.58$ (SD = 1.680) for frustration, while IIS participants scored $M = 6.10$ (SD = 2.904) for performance, and $M = 6.00$ (SD = 2.449) for frustration. For Task 2, CIS teams scored $M = 7.85$ (SD = 1.309), while IIS participants scored $M = 6.55$ (SD = 1.462) for frustration.



Note: Error bars represent SE

Figure 5.
Type of cognitive load in Task 1

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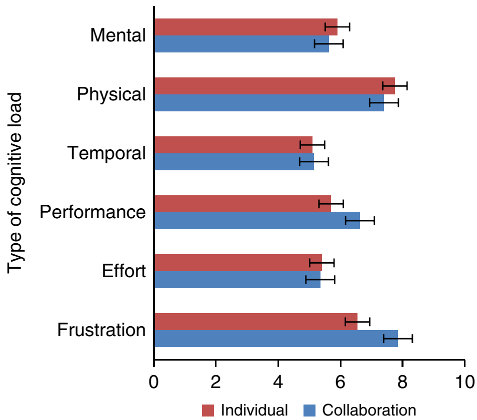
Interestingly, as can be seen in Figure 6, frustration scores were slightly higher in CIS teams than that in IIS participants, and the differences are significant in both tasks ($F = 4.302$, $p = 0.047$ in Task 1 and $F = 6.093$, $p = 0.020$ in Task 2). This is contrary to our hypothesis that CIS teams would experience less frustration than IIS participants. This may be caused by the burden of the communication and unfamiliarity with the information search system interface regardless of task complexity. Feild *et al.* (2010) defined frustration as the impediment of the information search process in the context of IR stating that while not finding the information can be frustrating, even when the information is found, users can get frustrated. Collaboration in the course of the information search process might have two perspectives as positive vs negative interaction (González-Ibáñez, 2012). Those who prefer working together might have varied information seeking strategies and query behaviors by collaboration than those who prefer working individually, which can contribute to better team performance in the end of a search task. Overall, CIS participants perceived higher performance under cognitive load than individual searchers did.

5.3 Search time and task type

RQ3 looked at participants' total search time for the search tasks. From the captured screen data, the total search time was calculated from the start of the search to when the participants were satisfied with the search results and finished their entire search process. As can be seen in Table V, the ANOVA test results show that there was no significant difference in Task 1 in terms of the total search time consumed, but there was a significant difference in Task 2 between the two conditions.



Note: Error bars represent SE

Figure 6.
Type of cognitive load in Task 2

Table V.
Search time required

	Search time (min)							
	Task 1				Task 2			
	Mean	SD	*F*	*p*	Mean	SD	*F*	*p*
Individual	8.60	4.061	2.095	0.165	18.90	5.384	5.202	*0.035**
Collaboration	11.40	4.575			24.10	4.795		

Note: $*p < 0.05$

To extend our investigation into the relationship between search time and different task type, we looked at mean differences of search time for each task under search conditions (i.e. IIS and CIS). As can be seen in Table V, the results of the ANOVA test show there are significant differences in searching time for the different task types, therefore the participants spend more searching time in Task 2 than in Task 1 under both search condition. This indicates that participants tend to require more searching time for the exploratory search task (Task 2) than the fact-finding task (Task 1) regardless of their search condition.

We can see that, on average, the mean values for both search tasks in CIS teams are higher than those in IIS participants. Search time in both conditions might be dependent upon the complexity of the task (Byström and Järvelin, 1995; Vakkari, 1999) (Table VI).

5.4 Query behavior and cognitive load

A Pearson correlation test was conducted to examine whether there were relationships among cognitive load, QP, QVR, and QRS. Interestingly, there were no significant relationships among total cognitive load and the query behavior variables. This is inconsistent with the study by Na (2012), in which searchers exposed to cognitive load manipulations issued fewer search queries than those not exposed to these manipulations. A possible reason for this finding is that the CIS searchers were able to reduce search query redundancy and uncertainty about the search goal, and to obtain synergetic effects by collaborating without causing an additional cognitive load (Shah and González-Ibáñez, 2011).

However, the results revealed that there was a significant relationship between QRS and QVR ($t = 0.868$, $p = 0.001$) in the IIS condition for Task 1. The results also revealed that there was a significant relationship between the variable pairs of QP and QRS ($r = 0.713$, $p = 0.021$), and QVR and QRS ($r = 0.932$, $p = 0.001$) in the IIS context for Task 2. There was also a significant relationship between QVR and QP ($r = 0.708$, $p = 0.022$) in the CIS condition for Task 1.

When correlations among type of cognitive load were compared, in the CIS context for Task 1, there was a significant relationship between the following variables pairs: mental demand and temporal demand ($r = 0.695$, $p = 0.001$), effort and mental demand ($r = 0.692$, $p = 0.001$), and temporal demand and performance ($r = -0.493$, $p = 0.027$). In the CIS context for Task 2, there was a significant relationship between effort and mental demand ($r = 0.713$, $p = 0.021$). In the IIS context for Task 1, there was a significant relationship between effort and physical demand ($r = 0.839$, $p = 0.002$). In the IIS context for Task 2, there was a significant relationship between variables pairs of mental demand and frustration ($r = -0.707$, $p = 0.022$), and physical demand and frustration ($r = 0.690$, $p = 0.027$).

In order to extend the investigation into the matter of how task difference (e.g. fact-finding or exploratory search task) and search condition (e.g. IIS or CIS) affect

	Individual				Collaboration			
	Mean	SD	*F*	*p*	Mean	SD	*F*	*p*
Task 1	8.60	4.061	23.328	*0.000**	11.40	4.580	36.722	*0.000**
Task 2	18.90	5.384			24.10	4.80		

Note: $^*p < 0.05$

Table VI. Mean of search time for search tasks

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searcher's cognitive load, we examined the relationship between the task difference and searcher's total cognitive load under each search condition. The results of the ANOVA reveal that there were no significant relationships between task difference and searcher's total cognitive load for both search conditions.

In summary, the association between mental and temporal demand appears to be important. Mental demand has a positive relationship with time when there is more time pressure. Likewise, the association between performance and temporal demand seems to be equally important in that there is a negative association, for example, when a searcher feels pressure to finish a search within a given time, meaning that perceived performance might be low. Lastly, there is a positive relationship between mental demand and effort. As the mental demand of an information search increases, the required effort might increase.

6. Conclusion and implications

Collaboration often occurs in workplaces. Research on collaboration in information seeking is of increasing interest, even though previous IR studies have been focussed on individual search contexts. To understand the effects of searching together vs searching individually, we conducted an exploratory user study of 30 participants, comparing collaborative information seeking and individual information seeking conditions during task-based web searching in a controlled laboratory setting. In this study, we compared query behavior these two conditions.

Our study indicates that more emphasis should be placed on how query behavior is presented to searchers during collaboration. The first finding of this study is that QP, QVR, and QRS can vary between collaborative information seeking and individual information seeking conditions. On average, participants who collaborated experienced significantly more QP, QVR, and QRS compared to those working as individuals. Overall, two people working together have a better chance of making more queries, more diverse queries, and more varied queries for information seeking goals by communicating freely and sharing their confidence in their judgments than one person working alone. Downey *et al.* (2008) examined the relationship between searchers' queries and information goals in which they found that searchers are more likely to be successful when the frequency of query and destination URL are similar.

The study results indicated that the cognitive load imposed on CIS vs IIS participants was not different except in relation to the performance component of NASA-TLX. We found that CIS participants had a higher degree of cognitive load than IIS participants did. In particular, searchers perceived significantly higher demands of performance and frustration when working together than one person working alone. However, there were no significant differences between CIS and IIS conditions in relation to the total cognitive load. This finding is consistent with the previous study by Shah and González-Ibáñez (2011). Our results also showed that the total search time was not different on average for the first search task but that there was a significant difference for the second task between the two conditions, which means that search time might be dependent upon the complexity of the task, and that CIS teams may take more time than those working individually due to the communication conducted during a search. We found that there was no significant relationship between query behavior and the total cognitive load.

The ways in which CIS is performed by searchers may affect the quality of search results due to the query process used throughout a search. When CIS can be performed in a more user-friendly form and fashion, it may be cognitively processed more efficiently than when information is searched by individuals, potentially lowering errors in information search processing and increasing synergy to information needs.

The field of collaborative information seeking has the potential to unify the group and help the members when searching for information and solving common information goals. For decades, information retrieval researchers have focussed on the individual performance of information retrieval. The emerging field of collaborative information seeking adds a complementary focus on the social function of information processing in IR.

The query behavior analysis approach in combination with the cognitive load analysis yields insightful information that can impact the development and adoption of future collaborative search engines such as applications for smartphones and social networking sites and can lead to a greater understanding of CIS. Morris (2013) stated that an increase in the prevalence and frequency of collaborative web search found that technologies such as social networking sites and smartphones support this phenomenon.

We believe that this closer look at the processes of query behavior, search time, cognitive load in collaborative search in different types of tasks will facilitate in two major ways: First, by providing useful insights about how formulate and reformulate queries effectively and reduce redundant website visits and cognitive loads among collaborators, helping to establish a useful environment for the sharing, organizing and using information in collaborative search and second, by enabling information professionals to provide proper information services in a CIS setting depending upon factors such as the different types of search task and task processes of searching, and the communication channels available. For examples, identifying each other's information needs, checking frequencies of queries and offering query suggestions during collaborative search could be useful for constructive and effective work. In addition, looking at the collaborators' search history and the URLs visited or bookmarked that are relevant to their information needs could helpful to reduce redundant website visits, decrease cognitive loads and save the searching time in collaborative search. Besides, making out information users' behaviors and patterns in collaborative search might be useful for the information professional to develop instruction of information literacy for users in CIS.

Cognitive load analysis in this study was done using a self-reported survey by exploring synchronous CIS sessions. However, the factors affecting searchers' cognitive load could be asynchronous search and synchronous search, positive aspect of collaborators' interaction vs negative aspect of collaborators' interaction, or collaborators' own learning style. In addition, ease of access and use of a collaborative information system should be also considered in terms of lowering the total cognitive load induced by a searcher. Those who prefer synchronous search might have a lower cognitive load toward the positive aspect of social interaction than those who prefer asynchronous search in collaborative search environments, or vice versa. Those who prefer synchronous search might perform better than those who prefer asynchronous search in terms of search effort as well as in search results, or vice versa. Therefore, it is important for system developers to consider how these factors affect a CIS process.

In short, information professionals should pay attention to the query process of information searchers in the collaborative setting. IR system developers should improve CIS systems to achieve better search performance; and pay attention to variations in the cognitive load of searchers during the CIS process.

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7. Limitations and future direction

This experiment was our initial study of the CIS process. As such, despite some interesting findings, there are several limitations that restrict the generalizability of the results. First, team searchers were paired for collaborative searching in this study. However, more people might be involved in an actual search environment and the findings might change in the context of a bigger team. Different team sizes should also be evaluated to improve the understanding of CIS performance compared to that of IIS. Second, collaboration in this experiment was only accomplished in one session for each task. However, in the common search setting, factual or exploratory web search tasks might occur over several sessions. Therefore, various approaches to search tasks should be considered.

In addition, only Koreans and undergraduate students in a library and information science program participated in this study. The simple circumstances of conducting a study using a single country and within a single discipline might restrict the generalizability of this study. Future research should consider varying sample characteristics, such as citizenship, academic discipline, search competency, and search experience. Third, the search task questions used in this study were translated into Korean from the original language of English. Thus, domain expertise about the search tasks might affect participants' search performance due to their previous knowledge about the questions' content.

Another weakness is that the study enrolled only 30 participants, so the power to detect small effects was low. For an exploratory study such as this, the number of participants is considered appropriate but the use of a large number of participants in future studies could allow for finding weaker effects. Additional studies exploring asynchronous information search sessions in a CIS context may provide further insights into CIS system design and development.

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Corresponding author
Jisu Lee can be contacted at: Jisulee0423@gmail.com

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