Relationship between Cognitive Styles and Users’ Task Performance in Two Information Systems

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ABSTRACT
Studies have shown that cognitive styles have some impacts on user performance in various types of systems. The current study focused on the effects of cognitive styles on users’ information-seeking task performance between an information visualization system and a generic information system. Thirty-two graduate students participated in a controlled laboratory experiment. Each of them completed an extended cognitive style analysis - wholistic analytic test (Extended CSA-WA test) on cognitive style, and then conducted eight information search tasks, four analytical and four aspectual, in one of two systems: a text-based system, Web of Science, or a visualization system called CiteSpace. Results demonstrated that users’ cognitive styles showed effect on task performance. The Wholistic-Analytic (WA) ratio obtained from the CSA-WA test was shown to be significantly correlated with result correctness for analytical tasks. Users with lower WA ratios were also found to have significant lower result satisfaction for analytical tasks than for aspectual tasks. Also, we found significant system effect on users’ search performance. These results indicate that cognitive style is an important factor affecting users’ performance, so is system interface design. Research in both areas provides valuable indication for future information system design.

Keywords
Cognitive styles, visualization, task performance

INTRODUCTION
During the past decade or so, many studies have been conducted to investigate the effects of cognitive styles on information processing. They found that cognitive styles influence an individual’s preference to organizing and processing information. Cognitive style is a construct being used to describe an individual’s habitual mode of perceiving, remembering, thinking and problem solving (Riding & Cheema, 1991). Cognitive styles are believed to be fairly stable throughout an individual’s life-time, and standard psychometric tests have been developed to assess one’s cognitive styles. In the area of information search, cognitive styles were found to impact people’s search performance (Park & Black, 2007; Palmquist & Kim, 2000). Researchers also discovered that cognitive styles affect users’ interaction with information systems on different information tasks (Gwizdka, 2009), and users performed differently between an information visualization system and a text information retrieval system (Yuan, 2013). These indicate the possibility of improving users’ task performance in information systems by taking account of cognitive styles in system design. A majority of previous research was conducted using the text-based information systems but not much used visualization systems, and there has been little effort, to our knowledge, spent on comparing the effects of cognitive styles on users search performances in the text-based and visualization systems. In the current study, we were particularly interested in exploring if and how cognitive styles impact users’ search task performance in two information systems, one being a text-based and the other being a visualization system, and if and how the relation between cognitive style and task performance vary in different task types.

RELATED WORK
There have been various types of cognitive styles studied in the literature, for instance, the 9 examples identified by Messick (1988) including field dependence-independence, cognitive complexity-simplicity, and leveling-sharpening, etc. On the basis of a comparative review, Riding & Cheema (1991) concluded that there are two basic dimensions of cognitive styles: one is the wholistic-analytic style of whether an individual tends to “process
information in wholes or in parts”, and the other is the verbal-imagery style of whether an individual tends to “represent information during thinking verbally or in images” (p. 210). Riding & Sadler-Smith (1992) further noted that the term wholistic-analytic is in fact equivalent to the term field dependent-independent, although in the literature, different studies used different labels.

Among others, field dependence-independence has been the most frequently studied pair of cognitive styles in the individual differences area. According to Vessey (1991), field dependent (FD) people typically experience surroundings in a relative global manner, are easily influenced by the environment, and are more passive to accept ideas as presented; conversely, field independent (FI) people usually experience surroundings with an internal perspective, process information with their own structure, and are more active to accept ideas through analysis. Some studies detected their effects on one’s information search behaviors and/or search performance. For instance, Palmquist & Kim (2000) found that in general, FD users tended to spend longer time than FI users in completing search tasks in a university website. Many other studies explored their influence on people’s searching and navigation behaviors as well as their reactions with different interfaces. Ford, Miller, & Moss (2005) found that FD people had a higher level of using Boolean search while FI people had a higher level of using Best Matching. Chen & Ford (1998) found that in the use of a web-based hypermedia learning system, compared with FI users, FD users tended to make heavier use of the main menu and previous/next buttons, take more navigational moves, and engage in more duplicated pages. Dufresne & Turcotte (1997) found that in a hypermedia learning system, FD users consulted the user guide longer than FI users in a restricted version of the interface where they can only follow the restricted links to other pages, and vice versa in the free access version. Chen, Magoulas, & Dimakopoulos (2005) found that field dependence-independence influenced users’ reactions to the organization of participant categories, presentation of the search results, and screen layout. Lee & Boling (2008) argue that interactions between information representation approaches and learners’ cognitive styles may have significant effects on learners’ performance. They claim that the performance of a learner, especially with a low level of knowledge, could decline if a representational approach that contradicts their cognitive style is used. Frias-Martinez, Chen and Liu (2009) found cognitive styles have great effects on users’ responses to adaptability and adaptivity.

Some other studies looked at wholistic versus analytic styles (Peterson, Deary, & Austin, 2003a; 2003b). Riding and Cheema (1991) explain the differences between users with a wholistic or analytic cognitive style by asserting that the wholists often view a situation as a whole, while the analytics see situations as a collection; often stressing only one or two aspects at a time. It is believed that wholistic versus analytic cognitive styles also have an impact on search behavior and search performance (2007), but fewer studies have been done in this direction. Ford, Wood and Walsh (1994) claim that field independent students have greater propensities towards analytical cognition. Park and Black (2007) conducted a study in which 61 graduate students were tasked with finding answers to six open-ended questions on the web. Participants who had analytic cognitive styles used significantly more keywords than did participants with an intuitive (wholistic) cognitive style. Ford, Miller, & Moss (2005) examined wholist/analytic and imager/verbalizer cognitive styles as relating to individual differences and their effects on Web search strategy. They found that high levels of Boolean searching were positively correlated to a wholistic cognitive style.

In sum, research has shown that cognitive styles are important factors influencing the interaction between users and systems, as well as search performance. The previous studies have mostly looked at text-based information systems but not much about visualization systems, nor the comparison of the text and visualization systems. This area needs further research attention.

Vessey (1991) proposed a Cognitive Fit Theory which attempts to explain the effects of graphical and tabular representations on human decision-making performance. The Theory states that information can be presented in two fundamentally different ways: graphical or tabular; problem solving tasks can also be divided into two types, being spatial or symbolic; and performance on a problem-solving task will be enhanced when there is a cognitive fit between the information emphasized in the representation type and that required by task type. The theory was tested by information acquisition studies and information evaluation studies. However, it was not tested by real information search tasks that people do in everyday life. The theory provides a link between information task and information sources, with no consideration of the person who conducts the task in regard to his cognitive style or cognitive ability. As people could have different types of cognitive styles, it is natural to ask if there could be relations between information task doer’s cognitive style, information sources, and/or information tasks.

RESEARCH QUESTIONS

To better understand the impact of cognitive styles on information systems, we generated the following three research questions:

RQ1: How do cognitive styles affect users’ search task performance in information visualization systems and in text-based systems?

RQ2: Do cognitive styles affect users’ search task performance differently in information visualization systems in comparison to in text-based systems? If so, how?
RQ3: Do cognitive styles affect users’ search task performance differently in different task types? If so, how?

**METHODOLOGY**

To address the above research questions, we conducted a user study in which we invited participants to work on some search tasks in the two search systems. Their cognitive styles were also elicited by a standard test. The details are introduced in the following subsections.

**Experimental Design**

The study was a 2*2 controlled design (Table 1). Half of the participants used one search system, and the other half used another system. Each participant performed eight tasks of two different task types, four of one type. The details about the two task types (aspectual, analytical) are available in Task. Task orders were randomly assigned using a Latin-Square design, which ensures that no participant is given the tasks in the same order. Each participant also completed a cognitive test before they start doing the given tasks.

**Participants**

A total of 32 graduate students from different departments in UAlbany participated in the experiment. They were recruited through notices posted to several departmental listservs and by in-class announcements.

**The cognitive test**

Riding (1991) designed the Cognitive Style Analysis (CSA) to measure wholistic and analytic cognitive styles by comparing how fast, on average, individuals respond on a verbal task compared to an imagery task and how fast they respond, on average, on a wholistic task compared to an analytic task. Peterson, Deary, and Austin (2003a, 2003b) demonstrated that Riding’s (1991) verbal-imagery style preference and wholistic-analytic style preference ratios had poor re-test reliability. They found that an extended version of the CSA’s wholistic-analytic dimension (Extended CSA-WA) improved the tests reliability to a satisfactory level.

The Extended Cognitive Styles Analysis-Wholistic–Analytic (Extended CSA-WA) test contains 40 wholistic questions in which the user is asked to judge whether two shapes are the same or different, and 40 analytic questions which ask the user to determine if a certain shape is embedded within another.

Participants are immediately provided with information on the accuracy of their choice and are encouraged, by the system, to respond accurately but at a comfortable pace. Style preferences for the Extended CSA-WA are measured by comparing their median reaction times on the wholistic questions with their median reaction times on the analytic questions so that each participant is given a wholistic–analytic reaction time ratio which identifies their relative position on a wholistic–analytic style continuum (Peterson & Deary, 2006). In short, the Extended CSA-WA test measures user preferences for wholistic versus analytic way of structuring information.

<table>
<thead>
<tr>
<th>Participants</th>
<th>System</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-16</td>
<td>CiteSpace</td>
<td>4 aspectual, 4 analytical</td>
</tr>
<tr>
<td>17-32</td>
<td>Web of Science</td>
<td>4 aspectual, 4 analytical</td>
</tr>
</tbody>
</table>

Table 1. Experimental design

We chose the Extended CSA-WA test in our study because this test reliably detects individual differences in tasks of a higher order, relative to wholistic and analytic stimuli (Peterson, Deary, & Austin, 2005b; Peterson & Deary, 2006).

**Search Systems**

The **Web of Science system**

The Web of Science system (WoS) provides researchers with quick and powerful access to the world’s leading citation databases (Figure 1). The content covers over 10,000 of the highest impact journals worldwide and over 110,000 conference proceedings in multidisciplinary fields. It displays the retrieved results in a ranked list with information such as title, authors, source, publication year, number of citations. Using the WoS system, users can find high-impact articles and conference proceedings, discover relevant information in related fields, recognize emerging trends of literature and research, and find potential collaborators with significant citation records.

![Figure 1. Screenshot of the search results page of the Web of Science system](image)

The **CiteSpace system**

The CiteSpace system (Figure 2) was chosen in this study because it is a well-known, actively maintained, stable and widely used knowledge domain visualization system. Also, the fact that it can be run on multiple computer platforms makes it easy for researchers to evaluate.

The CiteSpace system was created to identify intellectual turning points (Chen & Ford, 1998) through constructing co-citation networks among highly cited articles. It enables
users to manipulate the resulting graphical network in a variety of ways such as displaying multiple time periods and setting different thresholds.

The visualization graph of the CiteSpace system is composed of nodes and lines connecting the nodes. There are nine types of nodes in the CiteSpace system (version 2.2.R1), including authors, term, keyword, category, institution, cited reference, cited journal, cited author and country. Correspondingly, nine visualization graphs were designed to represent the patterns in scientific literature. Figure 2 displays the resulting visualization graphs which correspond to the node “country.” Other resulting graphs are similar to Figure 2. The CiteSpace system was tested in heuristics evaluation (Synnestvedt & Chen, 2005), cognitive walkthrough (Allendoerfer, 2005) and in a user-centered experiment (Yuan, Chen, Zhang, Avery and Xu, 2013), but has not been tested with users’ cognitive styles yet.

The Dataset
We constructed the dataset by searching the topic “life on Mars”, language “English”, document type “Articles”, and published between the years of “2000-2009” in the ISI Web of Science. Totally 857 records were retrieved from the Web of Science system. All these documents were saved in a database, which was used in the experiment of this study.

The Tasks
Our search tasks were designed as two types: the aspectual tasks and the analytical tasks (Table 2 for an overview). The aspectual tasks were to identify as many different aspects as possible for a given topic and save appropriate resources that cover all distinct aspects of that topic (Over, 1997). The analytical search tasks were defined as tasks which need more goal-oriented and systematic analytical strategies (Marchionini, 1995). Table 2 shows the topic/task description, type, and the corresponding node type in CiteSpace for each of these tasks. The CiteSpace node type indicates where the related information can be found on the CiteSpace system for this particular topic.

The following is an example analytical search task.

Scenario: As a graduate student, you want to write a paper about research on life on Mars. You are interested in how research has been done and what research has played an important role in this area during the past several years.

Task: You need to collect some papers for the literature review. You know that some papers published by Edwards HGM would be very helpful. Please find the author who has the most collaboration with Edwards HGM, then put your answer on the answer sheet.

The following is an example of the aspectual task.

Scenario: As a graduate student, you want to write a paper about research on life on Mars. You are interested in how research has been done and what research has played an important role in this area during the past several years.

Task: You want to identify all the countries which have many publications (>20) and also have collaborated with each other. Please put your answer on the answer sheet.

<table>
<thead>
<tr>
<th>Task type</th>
<th>Task category</th>
<th>Task description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analytical</td>
<td>Institution</td>
<td>Find the name of the university that has collaborated with Caltech in 2009 and published papers.</td>
</tr>
<tr>
<td></td>
<td>Author</td>
<td>Find the author who has the most collaboration with Edwards HGM.</td>
</tr>
<tr>
<td></td>
<td>Category</td>
<td>List two participant areas/categories that only authors from the USA are involved.</td>
</tr>
<tr>
<td></td>
<td>Author</td>
<td>Identify two years that large groups (more than 20 people) have published papers.</td>
</tr>
<tr>
<td>Aspectual</td>
<td>Institution</td>
<td>Find all the institutions which collaborated on the topic in 2008.</td>
</tr>
<tr>
<td></td>
<td>Country</td>
<td>Identify all the countries which have many publications (&gt;20) and also have collaborated with each other.</td>
</tr>
<tr>
<td></td>
<td>Keyword</td>
<td>List all the keywords that appear frequently with the word “life.”</td>
</tr>
<tr>
<td></td>
<td>Category</td>
<td>Identify all the participant areas/categories that more papers were published in 2008 than in any other year.</td>
</tr>
</tbody>
</table>

Table 2. Tasks

Task Performance Measures
Participants’ task performance measurement in the current study consisted of several aspects, which were adopted from previous studies (Yuan & Belkin, 2007, 2010). These measures included user satisfaction with the task results, time to task completion (in minutes), result correctness, aspectual recall, and number of mouse clicks during the task.

User satisfaction was measured by asking each participant in the post-task questionnaire to rate his or her own satisfaction with the search results on a 7-point Scale ranging from Not at all to Extremely (satisfied). Time to
task completion was recorded by the logging software Morae\(^1\) (version 2.1) and it was measured starting from the user opening the visualization window until the user finished typing the answers to the answer sheet. Result correctness was measured as the external assessor’s rating of the participant’s saved answer(s) which answer the search topic on a binary scale: Incorrect (0), and Correct (1). An external assessor was used to judge the result correctness because we wanted to obtain relatively objective judgments. Aspectual recall, a measure developed in the TREC Interactive Track (Dumais & Belkin, 2005), is the ratio of aspects of the search topic identified by the participant, to the total number of aspects of the topic. Number of mouse clicks reflects a participant’s actions during performing a task. It was measured by counting the total number of mouse clicks recorded in the logging software. Number of mouse clicks indicates to what extent the participant interacts with the system.

**Procedure**

Each participant was tested individually in the human computer interaction lab in UAlbany. When the participant came, he or she first read and signed a consent form, and then filled out an entry questionnaire about their background, computer experience and previous searching experience. Next, they were given the cognitive test (Extended CSA-WA test) to complete. Then they were given a tutorial of the system (either CiteSpace or Web of Science). After that, the participants did two training tasks of each task type (either analytical or aspectual).

Before each task the participants filled out a pre-task questionnaire about their topic familiarity and expertise. They were given up to 10 minutes to conduct each task. After completing each task, they completed a post-task questionnaire about their experience of completing the tasks. After the participants finished all the tasks, they were asked to complete an exit questionnaire about their opinions of using the system.

Each participant was compensated $25 for their completion of the experiment. The experiment was conducted in a human-computer interaction lab at UAlbany, and each participant was tested individually. Morae logging software was used to log all the interaction between each user and the system, including mouse click, keyboard activities, time stamp of each action, etc.

**RESULTS**

**Results of the Extended CSA-WA test**

The Wholistic-Analytic ratio (the WA ratio) was calculated as the ratio of the median reaction time on the wholistic items to the median reaction time on the analytic items and was automatically shown in an Excel report after each participant completed the test. Of the 32 participants, the minimum WA ratio was 0.959, and the maximum was 3.29. The median was 1.214. The mean was 1.298, and the standard deviation was 0.404. The lower ratios indicate a tendency towards a wholistic preference and the higher ratios indicate a tendency for an analytic preference. Figure 3 displays the histogram of the WA ratio, for all users as well as for each group of users using the two different systems. As can be seen, most users had WA ratios between 1 and 1.5.

![Figure 3. The histogram of number of participants per ratio bin](image-url)

In order to further test the impact of cognitive styles on task performance, we divided participants into two groups of higher and lower WA ratios. The threshold was the median of all participants’ WA ratio values, i.e., 1.214. Those whose ratios were higher than the median ratio were included in the HWA ratio group and those whose ratios were lower than the median ratio were included in the LWA ratio group. Each group consisted of 16 participants.

**Participants’ background**

Participants’ demographic characteristics are shown in Table 3, by each WA group and in total. Among them, 9 were female and 7 were male, with ages varying between 20-49, There were no significant demographical differences between the low and high WA groups of users.

Participants rated their computer and searching experience on a 7-point scale, from 1=”low” to 7=”high.” In general, they used computers very frequently, and had high searching experience with the WWW. Mann-Whitney test (W) was used to test whether there are significant differences between the LWA and HWA groups. The LWA group had significantly more Catalog searching experience than the HWA group. Both groups’ searching experience with information visualization systems was low (LWA: mean =2.25, SD =1.84; HWA: mean =1.88, SD =1.26). There were no significant differences between the low and high WA groups of users for all other variables examined.

In the pre-task questionnaire, participants rated their familiarity and expertise with task topics on a 7-point scale, from 1=”Not at all” to 7=”Extremely.” Apparently, the participants were not familiar with the search topics.

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1 http://www.techsmith.com/morae.html
adopted in this study. There were no significant differences in their topic familiarity between the low and high WA groups of users, meaning that they were on the same knowledge level with the search task topics. Altogether, the above users’ background data seemed to indicate that they had significant differences mainly in their cognitive styles.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
<th>LWA group</th>
<th>HWA group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td>20-29</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30-39</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40-49</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td>Male</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 3. Participants’ demographic characteristics

The effect of cognitive styles on task performance

**Correlation**

An important way to investigate the effect of the cognitive styles is to see whether there were significant correlations between the cognitive styles and the performance measures. Pearson Correlation statistical analysis was performed to find the relationship between the cognitive styles and these measures. Results in Table 4 indicated that the WA ratio (mean =1.298, SD =0.404) was significantly correlated with result correctness (mean =0.63, SD=0.484, p=0.017). The higher the WA ratio, the more correct the results. We did not find significant correlations between the WA ratio and other measures.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Mean (standard deviation)</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (mins)</td>
<td>5.38 (3.54)</td>
<td>r=-.058, p=0.357</td>
</tr>
<tr>
<td>User satisfaction</td>
<td>4.73 (2.04)</td>
<td>r=-.015, p=0.811</td>
</tr>
<tr>
<td>Result correctness (for analytical tasks)</td>
<td>0.63*(0.484)</td>
<td>r=0.211, p=0.017</td>
</tr>
<tr>
<td>Number of mouse clicks</td>
<td>48.75 (39.07)</td>
<td>r=-.091, p=0.147</td>
</tr>
<tr>
<td>Aspectual recall (for aspectual tasks)</td>
<td>0.532 (0.388)</td>
<td>r=-.045, p=0.615</td>
</tr>
</tbody>
</table>

Table 4. Correlation between WA ratio and the performance measures (* sig. at p<0.05 level)

**Group differences**

To further understand the impact of cognitive styles on task performance, we looked at users’ performance measures of different WA groups, as well as those using different systems. ANOVA results (Table 5) did not find any significant differences between these two groups in terms of task completion time and number of mouse clicks.

Pearson Chi-square test showed that the HWA group got significantly more correct answers for analytical search tasks (mean =0.72, SD =0.45) than the LWA group (mean =0.55, SD =0.50), $\chi^2=4.07, df=1, p=0.044$. The HWA group identified more aspects (mean =0.54, SD=0.37) for aspectual tasks than the LWA group (mean =0.52, SD=0.40), the difference was not significant from the ANOVA test, $F=0.121, p=0.728$. Wilcoxon signed-rank test results showed that the HWA group felt descriptively more satisfied with the results (mean = 4.78, SD=1.95) than the LWA group (mean =4.68, SD=2.13), $Z=-0.762, p=0.446$, but there was no significant difference.

<table>
<thead>
<tr>
<th>Significant measure</th>
<th>LWA group</th>
<th>HWA group</th>
<th>ANOVA F</th>
<th>Wilcoxon Z</th>
<th>p Value</th>
<th>Chi-square $\chi^2$</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (mins)</td>
<td>5.63 (3.63)</td>
<td>5.13 (3.43)</td>
<td>1.313</td>
<td>-0.762</td>
<td>0.253</td>
<td>4.07</td>
<td>0.044</td>
</tr>
<tr>
<td>User Satisfaction</td>
<td>4.68 (2.13)</td>
<td>4.78 (1.95)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Result correctness</td>
<td>0.55 (0.50)</td>
<td>0.72 (0.45)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of mouse clicks</td>
<td>50.94 (44.58)</td>
<td>46.57 (32.68)</td>
<td>17.08</td>
<td></td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspectual recall</td>
<td>0.52 (0.40)</td>
<td>0.54 (0.37)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.728</td>
</tr>
</tbody>
</table>

Table 5. Users’ performance (* significant at <.05 level)

The effects of cognitive styles and systems on task performance

The effects of cognitive styles and systems on performance measures were analyzed using General Linear Model (GLM) test. Results indicate that there was no interaction effect on either of the performance measures. However, system type has a significant impact on time ($F(1, 256)=77.12, p=0.00$), on result satisfaction ($F(1, 256)=12.94, p=0.00$), and on number of mouse clicks ($F(1, 256)=17.08, p=0.00$). This could be attributed to the different result representations of the systems, as indicated from the exit questionnaire, that participants liked “the visualization (of CS) as it provides a map and routes of publications”, and “be able to sort the information by categories which makes searching much easier”, and “the graphic interface made things stand out clearly.” Participant WA group has a significant impact on time ($F(1, 256)=4.335, p=0.038$). The rest of the results were not shown to be significant.

Given that the system type has an impact on some performance measures, it would be interesting to test whether there was any pattern of different system users across the two WA groups (Table 6). In the LWA group, the CS users tended to spend significantly less time, felt significantly more satisfied with results, than the WoS users. The WoS users had significantly more mouse clicks than the CS users. The HWA group got the similar patterns. The CS users tended to spend significantly less
time than the WoS users, and the WoS users had significantly more mouse clicks than the CS users. In the HWA group, the CS users identified significantly more correct answers than the WoS users. We found that for the LWA group, CS users felt significantly more satisfied with the results than WoS users, but in the HWA group, there were no significant difference between the two system users on the result satisfaction. It seems that people with wholistic preference tended to feel significantly more satisfied using the CS system than using the WoS system.

A further analysis on task performance across participant groups in each system shows that when using the CS system, the HWA group identified significantly more correct answers (mean=0.80, SD=0.41) than the LWA group (mean=0.50, SD=0.51), $\chi^2 = 5.75$, $p = 0.016$. There weren’t any significant difference between the two groups on the other task performance measures for neither of the two systems. We further considered the possible impact of users of wholistic preference felt significantly more satisfied using the CS system than using the WoS system.

Aspects that we examined. We also tested the task performance difference for each type of task across the two participant groups. It appeared that in the LWA group, participants working on the analytical tasks (M=5.125, SD=2.02), W = 4697.5, $p = 0.0067$. This indicates that users of wholistic preference felt significantly more satisfied on the analytical task results. There weren’t any other significant differences found.

### Table 6. Users' performance across participant groups in each system

<table>
<thead>
<tr>
<th>Performance (mean/ S.D.)</th>
<th>LWA</th>
<th>HWA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>3.39 (1.64)</td>
<td>6.65 (3.83)</td>
</tr>
<tr>
<td>WoS</td>
<td>3.85 (2.25)</td>
<td>7.93 (3.92)</td>
</tr>
<tr>
<td>$t(125) = -6.74$</td>
<td>$p = 0.000^*$</td>
<td>$t(51) = -6.14$</td>
</tr>
<tr>
<td><strong>Result satisfaction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>5.63 (1.61)</td>
<td>4.25 (2.20)</td>
</tr>
<tr>
<td>WoS</td>
<td>4.95 (1.96)</td>
<td>4.40 (1.89)</td>
</tr>
<tr>
<td>$W = 3215.0$</td>
<td>$p = 0.001^*$</td>
<td>$W = 6016.0$</td>
</tr>
<tr>
<td><strong>Result correctness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>0.50 (0.51)</td>
<td>0.57 (0.50)</td>
</tr>
<tr>
<td>WoS</td>
<td>0.80 (0.41)</td>
<td>0.55 (0.51)</td>
</tr>
<tr>
<td>$\chi^2 = 5.75$</td>
<td>$p = 0.016$</td>
<td>$\chi^2 = 4.098$</td>
</tr>
<tr>
<td><strong>Aspectual recall</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>0.48 (0.41)</td>
<td>0.54 (0.41)</td>
</tr>
<tr>
<td>WoS</td>
<td>0.60 (0.35)</td>
<td>0.43 (0.40)</td>
</tr>
<tr>
<td>$t(36) = -0.58$</td>
<td>$p = 0.565$</td>
<td>$t(32) = 1.65$</td>
</tr>
<tr>
<td><strong>No. of clicks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>40.73 (26.25)</td>
<td>55.58 (50.23)</td>
</tr>
<tr>
<td>WoS</td>
<td>38.02 (24.08)</td>
<td>65.38 (40.71)</td>
</tr>
<tr>
<td>$t(125) = -3.95$</td>
<td>$p = 0.000^*$</td>
<td>$t(51) = -3.95$</td>
</tr>
</tbody>
</table>

*DISCUSSIONS*

### The effects of cognitive styles on task performance

Our results showed that cognitive styles had effects on users’ performance in the analytical tasks. WA ratio was found to have a significant positive correlation with the result correctness in analytical tasks. The higher WA ratio, representing the tendency of participants being more analytical in cognitive style, demonstrated to have a higher accuracy on result correctness in the analytical tasks. When users were divided into two groups, it was also found that the high WA ratio group, i.e., those who tend to be more analytical, obtained significant higher result correctness scores in analytical tasks. These results are reasonable considering that those who were better in analytical cognitive aspect did better in analytical tasks. These were also consistent with Lee and Boling (Lee & Boling, 2008) that learners’ cognitive styles may have significant effects on learners’ performance.

On the other hand, in aspectual tasks, users of different cognitive styles did not show differences in the aspectual recall. Users who tended to be more wholistic did not demonstrate better performance than their counterparts. Aspectual tasks required users to identify multiple aspects of task topics, however, in finding each aspect, the users still need analytical skills. In other words, to obtain high performance in aspectual tasks requires both analytical skills and wholistic thinking skills. This may be the reason why the two groups of users who showed tendency in either analytical or wholistic did not show differences.

Our results also showed that while cognitive style showed effect on users’ result correctness in analytical tasks, it did not seem to affect other aspects of users performance, such as time spent on tasks and the number of mouse clicks. While previous studies (e.g., Chen & Ford, 1998; Chen, Magoulas, & Dimakopoulou, 2005; Dufresne & Turcotte, 1997; Ford, Miller, & Moss, 2005) found that cognitive style affect people’s search strategies, including the use of different menus, buttons, Boolean operators, etc., they did not examine the total amount of effort. Our results indicate that users of a certain cognitive style performing well in a certain type of task does not necessarily require them to spend more effort in completing the task.

### System differences

Our results showed that users’ performance differ significantly in two systems. In the CiteSpace system, users had shorter time finishing the task, and used less amounts of mouse clicks, meaning that they spent less efforts. They also demonstrated higher degrees of satisfaction with their search, indicating their preference with the interface.

That users liked the CiteSpace system was also supported by the users’ verbal protocols by the think-aloud method and the exit questionnaire. For example, users of the CiteSpace system mentioned that they like the system “visualization graph” because it is structured and...
organized, in particular it showed the relationship between different features. In contrast, users of the Web of Science system pointed out that it would be nice if “the information in the system can be clustered visually”, as one of them mentioned.

In sum, our study found that the CiteSpace interface, while it did not actually lead to better task outcome, did save users’ effort and was preferred by the users. Users still would like a visual system for the citation search tasks.

**Interaction between system & cognitive style**

Our research did not find significant interaction effect between search system and users’ cognitive style on task performance. This meant that in the examined task types, the effect of users’ cognitive style on users’ task performance did not depend on systems, and the effect of systems on users’ performance did not depend on users’ cognitive styles. This seems not to be consistent with some of the previous studies (e.g., Dufresne & Turcotte, 1997), that users of a certain cognitive style (field-dependent) consulted the user guide longer than their counterparts (field-independent users) in a restricted version of the interface. The seemingly different results between ours and those in Dufresne & Turcotte (1997) could be due to many factors, such as tasks, specific interface features, etc., and the detailed reason analysis will be conducted in future research.

**Interaction between task type & cognitive style**

Our results showed that the task performance of the LWA and the HWA users did not vary in either type of tasks, nor the behaviors of users in the two types of tasks vary in either WA group. However, the users of the LWA group did have higher result satisfaction with analytical tasks than with aspecual tasks, although the HWA group users did not feel differences in their result satisfaction with the two task types. These findings indicated that although the task performance measured by result correctness and actions did not vary between aspecual and analytical tasks, the LWA users tended to have lower degrees of satisfaction with their result when working with aspecual tasks. System designers should consider this and ideally to improve the feelings of those with LWA ratios in terms of result satisfaction with this type of tasks. Future studies can be conducted to explore more into this area regarding why this happened, and what kind(s) of assistant systems can provide, etc.

**Implications for system design**

Our results have implications for search system design in several aspects. First, cognitive styles showed effect in one type of tasks, the analytical tasks, but not the aspecual tasks. It would be beneficial for the systems to be designed in a way that can provide assistance to the wholistic style users in analytical tasks, to help them improve search performance, while not hurt the performance of the analytical style users. Since each person’s cognitive style is usually consistent in the life, once knowing the user’s cognitive style, the system on the client side can save this information for long-term use, while protecting users’ privacy. Once the system detects task features based on some of the users’ behaviors, it can go ahead to provide supports to the wholistic style users. Second, system design should take account of the users efforts spent on tasks, in addition to their performance. Even though some systems, such as CiteSpace, does not necessarily improve users’ performance, it reduces users’ search efforts such as mouse clicks, time spent, etc., and therefore would be liked by users. Third, system design should also consider users’ subjective feelings of their task performance, e.g., the result satisfaction, and attempts to improve this aspect for the certain group of users.

**CONCLUSION**

In this study, we tested if and how cognitive styles would affect task performance of information systems. Thirty-two participants participated in the experiment and each of them performed eight tasks using either an information system called Web of Science or CiteSpace. We conclude that the cognitive styles (wholistic vs. analytic) appear to have certain impacts on users’ task performance in information systems.

We were constrained by a limited number of tasks and topics, number of participants, and a non-naturalistic lab environment. To address these limitations, we plan to conduct more user studies in the near future. Despite the limitations, this study contributes to information science the findings of the impacts that users’ cognitive styles (wholistics vs. analytic) have on their search performance, as well as the relations between cognitive styles and user performance with different task types and in different systems. We also provided several aspects of implications that our findings have on system design.

Information search is a complex process involving many cognitive, behavioral, and other types of factors. In the future, we aim to generalize the results of this study to other type of information systems, for example, testing how wholistic vs. analytical can have an impact on user performance in collaborative information systems.

We believe that user performance in information systems can be improved by taking into account of their cognitive styles. For example, as we found, answer correctness has relationship with cognitive styles.

It may be helpful if the interface design can tailor to users’ different cognitive styles in order to improve the answer accuracy.

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REFERENCES


