Time and Space in Collaborative Information Seeking: The Clash of Effectiveness and Uniqueness

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ABSTRACT
Collaboration takes place at different time-space conditions. Past research has shown that these two dimensions may have different implications in the collaboration process, as well as on its outcomes, depending upon the task being performed. In collaborative information seeking (CIS), as a relatively new topic in information science, little is known about the effects of different temporal-spatial contexts. To address this, we conducted a user study involving 80 participants in 40 pairs, which were assigned to four experimental conditions, namely: co-located, remotely located with text chat, remotely located with audio chat, and asynchronous. Using quantitative methods, we investigated the effects of these conditions on communication, information synthesis, productivity, and user experience. Results regarding the space dimension suggest that information seeking behaviors of co-located users tend to overlap thus affecting their coverage of diverse and useful information. Conversely, when team members are remotely located, limited interaction allows them to work more independently, leading them to explore more diverse and useful information with the added value of less cognitive and affective load. With respect to the time dimension, we found that asynchronous collaboration enables participants to reach high levels of independency at the cost of effectiveness. These results provide practical implications about how various spatial-temporal contexts in CIS could influence factors such as productivity, efficiency, effectiveness, and uniqueness.

Keywords
Collaboration, information seeking, communication, experimentation, time, space, human factors

INTRODUCTION
Information seeking is often considered a social process that involves communication and the interaction of people (Tiwadale et al., 1997). Collaborative information seeking (CIS), in particular, requires “systems and practices that would enable individuals to collaborate during the seeking, searching, and retrieval of information” (Foster, 2006, p. 330).

In today’s educational and organizational environments, teams collaborate at different times and spaces to perform their tasks. The time dimension in collaborative settings considers that team members may work at the same time (synchronously) or at different times (asynchronously). In terms of space, group members can work at the same place (co-located) or at different physical locations (distributed). Recent studies within the context of information seeking indicate that people may seek information synchronously or asynchronously at co-located or distributed environments (Golovshinsky et al., 2008; Pickens & Golovshinsky, 2007).

Early studies showed that team processes and outcomes vary across different time and space. These studies focused on variety of tasks and dimensions, but there is very limited research on how team processes and outcomes differ in a CIS task across time and space. Morris (2007) proposed that systems that support collaborative search across these dimensions could enhance the collaboration process. In that sense, understanding team processes across different time and space conditions is a key aspect to design better human-computer interaction (HCI) and information retrieval (IR) systems. Along with these lines, the goal of the work reported here is to investigate how time and space affect collaborative information seeking behaviors, communication, and performance of teams. In order to reach this goal, a user study was conducted with 80 participants in 40 pairs in four different conditions: co-located, remotely located with text chat, remotely located with audio chat, and asynchronous. As such, first the relevant literature is reviewed. Second, the study design is introduced. Finally, analyses and results are presented, followed by discussion on the implications for CIS system design.

BACKGROUND
Team Processes during Collaboration
There have been calls for more research to understand the role of relational and social factors in the way team
members share information with others (Cross et al., 2001). Both early and recent research highlighted several teamwork behaviors that are essential for interdependent teams. For instance, an extensive literature review suggests that collaborative work demands extensive information sharing, coordination, and awareness (Shah, 2010a). Coordination is a process of working constructively for a shared goal. Awareness is defined as “an understanding of the activities of, which provides a context for your own activity” (Dourish & Belloti, 1992, p.1). Awareness allows team members to evaluate each other’s actions with respect to group goals and progress, and hence is fundamental to the coordination of activities and sharing of information. Within the framework of information seeking, through surveys and interviews, a body of literature has examined how people use the Web and the way they conduct Web search. Some of these studies revealed key features for supporting collaborative Web search, namely: awareness, division of labor, and persistence (Morris & Horvitz, 2007), and also brainstorming for keywords or query reformulation (Morris, 2008).

The current literature on collaborative processes mostly concentrates on synchronous and co-located teams (Smeaton et al., 2006), or on remote users collaborating synchronously (Villa et al. 2008). However, not only space (co-located vs. distributed), but also time (synchronous vs. asynchronous) may affect collaboration processes, and as a result the performance of teams in different ways. As such, the next section summarizes the team processes that take place at different time and space.

**Team Processes in Co-located and Distributed Contexts**

The role of communication context for effective team functioning has been largely investigated within the theoretical framework of media richness theory. Media richness theory asserts that communication media differ in terms of the richness of the information that can be transmitted (Daft & Lengel, 1984). According to this theory, face-to-face (F2F) communication is the richest communication medium because it allows for multiple cues such as nonverbal as well as immediate feedback. One of the propositions of this theory is that task performance improves when task needs are matched to the richness of communication medium. However, there is also evidence that individuals adapt to the medium as they experience using it. For example, Newlands et al. (2003) found that task performance of computer-mediated communication (CMC) participants was initially poorer when compared to the performance of F2F interactions, but improved as they gained experience of the CMC context. Participants in this study adopted a precise, specific way of giving directions, which was not found in F2F interactions.

Several studies investigated how teams in F2F and CMC differ in their performance on different tasks. These studies showed that tasks that require significant amount of coordination, or that negotiation requires a rich media (Straus & McGrath, 1994). Participants working on a collaborative Web search task indicated both obstacles and advantages of working remotely (Morris, 2008). On one hand, working remotely enabled them to follow different strategies to search for information, increasing their productivity. On the other hand, while working remotely, they faced the problem of gathering redundant information and having difficulty navigating the collaborator to the same content. These findings may demonstrate the need for varying degrees of communication and coordination during a search process for positive outcomes.

**Team Processes in Synchronous and Asynchronous Contexts**

When synchronous communication is not possible, time and space barriers of the traditional teamwork environment can be overcome through asynchronous communication contexts. Asynchronous collaboration has both strengths and weaknesses, which could be understood within the framework of social presence theory (SPT). SPT suggests that social presence will affect the way individuals perceive their discussions and their relationships with others (Sonnenwald & Pierce, 2000). According to this theory, communication media vary in their degree of social presence and people tend to choose media compatible with their needs for social presence. For instance, F2F communication is the highest in social presence followed by video, multichannel audio, and written text. Prior research suggests that a lack of fit between the medium and a task’s social need can negatively influence the experience of social presence (Chou & Min, 2009), as well as communication performance (Mennecke et al., 2000). Early studies concluded that due to reduced social presence in asynchronous context, coordination can be difficult, as group members are not always accessible when needed. With regard to CIS process, awareness (Morris & Horvitz, 2007) and sensemaking (Paul & Morris, 2009) are reported as important aspects of CIS, which call for high social presence. Awareness may help collaborators focus on useful and important information. Likewise, while working on information-intensive task, collaborators may necessitate making sense of information to reach their goal (Paul & Morris, 2009). Asynchronous communication context might be a barrier for team members to maintain awareness and sensemaking, thereby affecting team outcomes.

**Research Questions**

To address the need to design systems that support communication in these varying dimensions, the following research questions are put forth.

*RQ1*: How does collaboration at different time and space conditions (F2F, text chat, audio+text chat, and
asynchronous) affect teams’ interactions within a CIS task?

RQ2: How does collaboration at different time and space conditions (F2F, text chat, audio+text chat, and asynchronous) affect the productivity of teams within a CIS task?

RQ3: What are the effects of different time and space conditions (F2F, text chat, audio+text chat, and asynchronous), if any, on information synthesis within a CIS task?

Finally, the current literature also shows that communication context may influence cognitive load (limitations on working memory capacity) and affective load (e.g., anxiety levels) of team members (Howarth & Anderson, 2007; Satar, 2008). In order to understand the cost and benefit of time and space in regards to these two aspects, the following research question is formulated.

RQ4: How do different time and space conditions (F2F, text chat, audio+text chat, and asynchronous) affect (a) cognitive and (b) affective load of teams within a CIS task?

In order to address each of these research questions we designed a laboratory study. Its particulars are presented in the following section.

**METHOD**

A laboratory study involving a total of 80 participants in 40 collaborative pairs was conducted. We fixed the number of members per team as the minimum group size (two) in order to avoid possible intervening variables. This decision was made based on previous studies in which it has been stated that as the group size increases, it also increases the number of interactions among group members, thus affecting interpretation of results (Tang et al., 2010). In this section we describe our design decisions and the details of our study.

**Participants**

Participants in this study were students recruited from Rutgers University through open calls that were spread through various email-lists. We required participants to sign up in pairs with someone with whom they had previous experience working together. This design decision was made in order to ensure that participants had common ground (Clark & Brennanm, 1991) and make the collaborative task more realistic.

From the 80 participants we recruited, 49 were female and 31 male, with ages ranging between 18 and 30. In terms of fields of studies, these included: economics, math, psychology, and information science, among others. Most of the participants (70%) reported using Windows. Moreover, 84% of the participants indicated having intermediate to advanced search skills.

As a retribution for their participation, each subject was paid $10 for a 60-70 minutes experiment session. In addition, they were informed in advance that the three best performing teams would receive additional compensation per participant at the end of the study. Such compensation consisted of $50 for the first place, $25 for the second place, and $15 for the third place. We also controlled that subjects participated only once.

**Collaboration System**

We used a new version of Coagmento (Shah, 2010b; Gonzalez-Ibanez & Shah, 2011), an open source plug-in for the Firefox Web browser, which provided a set of tools for supporting information seeking, sharing, synthesis, as well as communication for teams (pairs).

As depicted in Figure 1, Coagmento consists of two major components, namely: toolbar and sidebar. First, the toolbar contains four buttons: (1) Home: which redirect users to pages containing instructions or questionnaires at different stages of the study; (2) Bookmark: that enables users to save, comment, rate, and share any webpage that users find to be relevant for the task being addressed; (3) Snip: for saving and sharing portions of texts of a given webpage, along with comments and rating; and (4) Editor: which opens a collaborative editor for writing the report required in the task (see description below).

**Logging Tools**

Beyond the features for supporting collaboration among team members, Coagmento is also a powerful logging tool capable of recording users’ actions within the Firefox web browser. This includes: pages visited, timestamps, queries, text messages, bookmarks, and snippets, among other useful data. We used Coagmento to record the Web browsing activity of users, messages exchanged during the collaboration process, and data from questionnaires that were introduced as part of the system.

Additionally we recorded desktop activity and participants’ faces using Camtasia Studio 7. For the condition in which participants were remotely located...
using an audio communication channel, we embedded Skype in Coagmento and we used Pamela Call Recorder to record the conversations of participants.

**Session Workflow**

We adapted Coagmento to guide users through various stages in the session workflow of this study. In each session participants were instructed by the researcher conducting the study to follow the steps in Table 1, using the text chat channel provided by Coagmento.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Participants were introduced to the study and asked to sign a consent form.</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Participants watched a brief tutorial in order to learn the basic functionalities required during the task.</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Participants individually filled out a set of pre-task questionnaires.</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Participants read the task description (presented later).</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Each team worked for approximately 30 minutes on the given task that included searching and collecting relevant information, and using it to compose a report.</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>Participants filled out post-task questionnaires.</td>
<td>6</td>
</tr>
</tbody>
</table>

**Task**

With regard to the task, all teams were asked to collect relevant information in an exploratory search designed to be a realistic work-task (Borlund, 1999). We selected “gulf oil spill” as the topic of the task, which according to few pilot runs was found to be appropriate in terms of the amount of material available on this topic and how engaging it was for the participants. The task description was presented as follow:

“A leading newspaper has hired your team to create a comprehensive report on the causes, effects, and consequences of the recent gulf oil spill. As a part of your contract, you are required to collect all the relevant information from any available online sources that you can find. To prepare this report, search and visit any website that you want, and look for specific aspects as given in the guideline below. As you find useful information, highlight and save relevant snippets. Make sure you also rate a snippet to help you in ranking them based on their quality and usefulness. Later, you can use these snippets to compile your report, no longer than 200 lines, as instructed. Your report on this topic should address the following issues: description of how the oil spill took place, reactions by BP as well as various government and other agencies, impact on economy and life (people and animals) in the gulf, attempts to fix the leaking well and to clean the waters, long-term implications and lessons learned.”

**Experimental Conditions**

In order to investigate how time, space, and communication relate to various aspects of CIS, we designed an experiment with four different conditions:
DATA ANALYSIS

Both quantitative and qualitative data was collected and analyzed through a specific method consisting of three stages: (1) data pre-processing, (2) coding, and (3) evaluation. This section provides a brief description of the first two stages, while the third one is presented in a separate section.

Table 2: Coding scheme.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
</table>
| TC       | Statements involving decision making about how the task should be performed | 1. We should start writing now.  
2. Can you search the second one?  
3. How do you want to do this?  
4. I will work on the reactions and you work on the consequences. |
| TC       | Statements that are related to the content of the task, which include information assessment, layout, structure, and revision of report | 1. I found something about consequences.  
2. Ok, I found stuff on the impact on economy life, people and animals.  
3. Well, I have how they finally capped off the leak, but I’ll look up some failed attempts. |
| TC       | Statements that concern group functioning, effort, or attitude as well as opinions in regards to information obtained or information sources. | 1. This task is really hard.  
2. We did good.  
3. Wow, so many animals were killed during the spill.  
4. I think my answer is the best. |
| TS       | Statements with a social orientation that are not related to the assignment or regarding technical issues of system being used | 1. I am hungry.  
2. I saw a great movie yesterday.  
3. What are you going to do tomorrow? |
| NT       | Statements that do not belong to any of the above categories                 | 1. What happened?                                                                             |

EVALUATION

In order to perform comparisons across conditions, we used five sets of measures, namely: communication, productivity, information synthesis, cognitive load, and affective load.

Communication

Using the coded data we computed frequencies for being used in statistical comparisons. In addition, we defined three additional communication measures, which are described as follow:

Volume ($V$): Overall number of messages (msg) exchanged by team members during the task. This was computed for each team simply by adding the number of messages issued by its members during the task (Eq. 1).

$$V = \#\text{messages} \quad (1)$$

Effort ($E$): Overall time spent in communication. This implicit measure of effort was operationalized through the duration in seconds of each message. This was computed for each team following two procedures depending upon the experimental condition. For the conditions with audio-based communication ($C_1^{\text{EXT}+\text{A}+\text{T}}$, $C_3^{\text{AUDIO+TEXT}}$, and $C_4^{\text{ASYNCH}}$), we subtracted the ending time and the starting time of each message (Eq. 2). For the condition with text-based communication ($C_2^{\text{TEXT}}$), this was estimated considering the average number of words per minute (wpm). Based on the literature and considering that this was not a transcription task, we established this rate at 50 wpm (Ostrach, 1997). Then we computed the number of words for each message to calculate the estimate time spent in writing it (Eq. 3).

$$E = \frac{\sum \text{duration in seconds of each message}}{\text{number of messages}} \quad (2)$$

$$E = \frac{\sum \text{number of words}}{50} \quad (3)$$
This implicit measure considers how balanced was the communication within a team (if participants exchanged similar number of messages). This was done by subtracting the communication volume (Eq. 4) as well as effort (Eq. 5) of each participant ($P_A$ and $P_B$) within a team, and then getting the modulus of the result.

The closer this value to zero, the more balanced the communication within the team.

$$B_e = |V(P_A) - V(P_B)|$$ \hspace{1cm} (4)

$$B_k = |E(P_A) - E(P_B)|$$ \hspace{1cm} (5)

**Productivity**

We measured productivity using six measures described in (Shah and Gonzalez, 2011). First, coverage ($C$), which corresponds to the union of all distinct pages visited by a given team during the search session. Second, relevant coverage that corresponds to the particular region of distinct pages within $C$ that were bookmarked as relevant or from where relevant snippet of text were collected. Third, the number of unique pages and relevant unique pages that were covered only by one team. Fourth, the group of pages in which team members spent 30 or more seconds, this as an implicit measure of usefulness (White & Huang, 2010; Fox, 2005). Then, we computed the query diversity for every pair of queries of different participants within a team. Finally we computed for each team traditional IR measures: precision, recall, and F-Measure. A summary of these measures is presented in Table 3.

<table>
<thead>
<tr>
<th>Productivity Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage</td>
<td>The total number of distinct webpages visited by a given team.</td>
</tr>
<tr>
<td>Unique Coverage</td>
<td>The total number of pages visited only by given team.</td>
</tr>
<tr>
<td>Relevant Coverage</td>
<td>The total number of distinct relevant webpages visited by a given team.</td>
</tr>
<tr>
<td>Unique Relevant Coverage</td>
<td>The total number of relevant pages visited only by given team.</td>
</tr>
<tr>
<td>Precision, Recall, and F-Measure</td>
<td>Three of the most common evaluation measures in information retrieval. We compute these measures using a reference to the union of the coverage and relevant coverage of all teams.</td>
</tr>
<tr>
<td>Useful coverage</td>
<td>An implicit measure based on the dwell time on a webpage (at least 30 seconds).</td>
</tr>
<tr>
<td>Query diversity</td>
<td>The Levenshtein distance between pairs of queries for a given subject/team.</td>
</tr>
</tbody>
</table>

**Information Synthesis**

As described in the method section, teams were required to produce a report in which they provided their answers to the questions stated in the task description. In order to create the report, participants used a collaborative text editor that was integrated with Coagmento. With the aim to evaluate the quality of the reports produced by teams, we performed two evaluation procedures: (1) we evaluated each report using standard readability tests, and (2) we asked human assessors to grade the reports with a standard rubric created for this task.

The first procedure constitutes the objective component of the evaluation of reports. This was based on two standard readability tests, namely, Flesch Kincaid Grade Level (FK) and Flesch Reading Ease (Kincaid et al., 1975). These tests are based on different units of analyses such as characters, syllables, words, and sentences, which are used to determine how difficult, or what level of education would be required to understand a given text. We computed both measures in order to ensure consistency.

On the other hand, the subjective component of the reports assessment was performed by two external graders. Each grader was instructed about the objective of the task that the participants had to perform and the evaluation criteria. The grading procedure was conducted using a rubric with four dimensions (content, resources, organization, and style), each of them in a 5-points Likert scale, being 1 poor and 5 excellent. As a result, the highest score a team could get in this evaluation was 20 points.

For the evaluation of the content of the reports, graders focused on the amount and quality of the information provided to answer the questions being asked in the task. Resources, on the other hand, were evaluated based on the number as well as the variety of resources used in the report. With regard to the organization of reports, this was evaluated considering the extent to which the information was synthesized and grouped. Finally, the style was evaluated in terms of spelling, grammar, punctuation and capitalization. The overall inter-rater reliability was found to be $\text{Kappa}=0.7$ ($p<0.01$).

**Cognitive and Affective Load**

Since one of our goals was to investigate the cognitive and affective experience of individuals engaging in a CIS task, we used two self-assessment instruments. For cognitive load, we used a simplified version of the NASA-TLX (Hart & Staveland, 1988). On the other hand, for measuring affective states before and after the task, we used the PANAS (Positive Affect Negative Affect Schedule) (Watson et al., 1988). Using responses from NASA-TLX and PANAS, we adapted Nahl’s (2007) formulation to estimate the affective load of participants. In the original expression, Affective Load $=$ Uncertainty $\times$ TimePressure; where uncertainty can be expressed through specific negative affects such as anxiety, frustration, and irritation, which in our study were reported through PANAS. For time pressure, we used the responses to a specific question in the NASA-
TLX questionnaire: “How hurried or rushed was the pace of the task?”

RESULTS

Based on the evaluation measures introduced above, this section presents the main results obtained for communication, productivity, information synthesis, and cognitive and affective load.

Communication

Using analysis of variance (ANOVA) over the computed frequencies of the coded messages, we found that task coordination (TC) in C12F was significantly higher than in C2TEXT, F(3,35)=4.431, p<0.01. In terms of task content (TN), it was found that C2TEXT was significantly lower than any other condition, F(3,35)=6.697, p<0.01. With regard to task social (TS) communication, our analyses did not reveal any significant difference across conditions. Finally, with respect to non-task (NT) related conversations, we found that participants in C12F were more likely to talk about topics outside of the context of task than teams in C2TEXT and C4ASYNCH, F(3,35)=6.930, p<0.01. Figure 2 and 3 summarize the communication of teams in each condition.

In a comparison in terms of the number of messages exchanged during the task (communication volume: V), we found that teams with face to face interactions (C12F) had greater exchange of messages than teams in C2TEXT and C4ASYNCH, F(3,35)=10.536, p<0.01 (Figure 4). Similar was the case for teams in C3AUDIO+TEXT, who exchanged significantly more messages than those in C2TEXT and C4ASYNCH (p<0.05).

We also compared the communication of teams in terms of the required effort (E). As described in the previous section, this was estimated in terms of the time spent in communication. Our analysis showed that the communication effort of teams in C12F was greater than that in C2TEXT, F(3,35)=4.82, p<0.01, and that in C4ASYNCH (p<0.05). It was also found that the communication effort of teams in C3AUDIO+TEXT was greater than that in C2TEXT (p<0.05).

Figure 4: Average communication volume in each minute during the task.

Table 4. Means and standard deviation for each communication measure in each condition. Arrows indicate that significant differences were found for the corresponding measure, being ↑ for significantly higher and ↓ for significantly lower. Values for Bv* and Bv must be interpreted in the opposite direction: Lower values mean more balance.

<table>
<thead>
<tr>
<th></th>
<th>C12F mean (s.d.)</th>
<th>C2TEXT mean (s.d.)</th>
<th>C3AUDIO+TEXT mean (s.d.)</th>
<th>C4ASYNCH mean (s.d.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>22.11 (11.95)↑</td>
<td>8.00 (4.37)↓</td>
<td>34.20 (30.62)↓</td>
<td>12.70 (9.35)↓</td>
</tr>
<tr>
<td>TN</td>
<td>29.89 (18.17)↑</td>
<td>8.20 (5.14)↓</td>
<td>48.80 (35.63)↑</td>
<td>20.40 (10.65)↑</td>
</tr>
<tr>
<td>TS</td>
<td>6.56 (4.36)</td>
<td>3.00 (3.16)</td>
<td>23.50 (28.55)↑</td>
<td>4.90 (5.32)↓</td>
</tr>
<tr>
<td>NT</td>
<td>28.78 (14.67)↑</td>
<td>1.00 (1.63)</td>
<td>44.30 (48.75)↑</td>
<td>0.90 (2.23)↓</td>
</tr>
<tr>
<td>V</td>
<td>150.22 (39.44)↑</td>
<td>28.80 (18.35)↓</td>
<td>209.00 (158.97)↑</td>
<td>43.10 (20.62)↓</td>
</tr>
<tr>
<td>E</td>
<td>390.55 (125.98)↑</td>
<td>185.16 (106.07)↓</td>
<td>636.00 (424.41)↑</td>
<td>219.60 (69.82)↑</td>
</tr>
<tr>
<td>Bv</td>
<td>40.00 (9.04)↓</td>
<td>13.00 (8.14)↑</td>
<td>38.80 (27.10)↓</td>
<td>8.10 (4.84)↑</td>
</tr>
<tr>
<td>Bv*</td>
<td>155.11 (51.06)↑</td>
<td>111.24 (47.13)↑</td>
<td>200.50 (107.20)↓</td>
<td>84.80 (65.31)↑</td>
</tr>
<tr>
<td>Q</td>
<td>27.33 (9.5)↑</td>
<td>4.5 (2.92)</td>
<td>34.40 (23.07)↑</td>
<td>10.10 (6.40)↓</td>
</tr>
<tr>
<td>A</td>
<td>19.78 (8.80)↑</td>
<td>2.3 (1.95)↑</td>
<td>23.50 (15.64)↑</td>
<td>6.90 (3.84)↑</td>
</tr>
</tbody>
</table>

A comparison of communication balance in terms of the number of messages exchanged (Bv) indicates that teams in C2TEXT and C4ASYNCH achieved greater balance than those in C12F, F(3,35)=11.881, p<0.01. It was also found that teams in C4ASYNCH had better balance than those in C3AUDIO+TEXT (p<0.05).

Similarly, an analysis of balance in terms of the communication effort (Bv), revealed that teams in C4ASYNCH had significantly better balance than teams in C3AUDIO+TEXT, F(3,35)=4.928 (p<0.05). We also looked at particular communication dynamics between team members, this was based on the number of questions, answers, statements, and suggestions exchanged during the task. It was found that team members in C12F issued
more questions than those in C2TEXT and C4ASYNC: F(3,35)=11.415, p<0.01. In a similar way, participants in C3AUDIO+TEXT issued more questions than those working in C2TEXT and C4ASYNC (p<0.05).

Consistently, the number of answers of teams in C12F was higher than that of teams in C2TEXT and C4ASYNC. Likewise, team members in C3AUDIO+TEXT responded more questions than those in C2TEXT, F(3,35)=11.845, p<0.01. At p<0.05, participants in C3AUDIO+TEXT provided more answers than those in C4ASYNC; and those in C4ASYNC responded more questions than those in C2TEXT.

A summary of the means, standard deviation, and indicators of significant difference for each communication measure is presented in Table 4.

Productivity

In addition to communication analyses, we also performed an analysis of productivity. Using ANOVA we compared the productivity of teams in each conditions based on the measures summarized in Table 3. Results indicate that regardless of the difference in time and space, teams seem to produce similar outcomes in terms of coverage (overall coverage, unique coverage, relevant coverage, and unique relevant coverage), precision, and recall. We found, however, that space and time have implications at the level of useful coverage and query diversity (Table 5).

Table 5. Means and standard deviation for each productivity measure in each condition. Arrows indicate that significant differences were found for the corresponding measure, being ↑ for significantly higher and ↓ for significantly lower.

<table>
<thead>
<tr>
<th></th>
<th>C12F mean (s.d.)</th>
<th>C2TEXT mean (s.d.)</th>
<th>C3AUDIO+TEXT mean (s.d.)</th>
<th>C4ASYNC mean (s.d.)</th>
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</thead>
<tbody>
<tr>
<td>UI</td>
<td>19.00 (5.01)</td>
<td>17.50 (5.06)</td>
<td>22.40 (5.82) ↑</td>
<td>15.40 (5.45) ↓</td>
</tr>
<tr>
<td>QD</td>
<td>19.69 (8.86) ↓</td>
<td>23.13 (8.47) ↑</td>
<td>22.29 (8.87) ↓</td>
<td>27.40 (17.01) ↑</td>
</tr>
</tbody>
</table>

First of all, teams working in C3AUDIO+TEXT were able to cover significantly more useful information (UI) than those in C4ASYNC, F(3,36)=3.483, p<0.05.

In terms of query diversity (QD), it was found that teams in which participants work at the same location and at the same time (C12F) tend to formulate more similar queries than teams working remotely located or asynchronously, F(3,2152)=32.994, p<0.01. This situation could limit the exposition of team members to different information sources, thus affecting the possibility to cover more diverse information.

On the other hand, teams working asynchronously (C4ASYNC), formulated a wide spectrum of queries compared to those teams working in synchronous conditions, F(3,2152)=32.994, p<0.01. As a result, team members in C4ASYNC had the possibility to explore more diverse information sources.

Information Synthesis

Using ANOVA we compared the evaluation of the reports produced by teams across conditions. Comparisons in terms of readability scores (objective measures) did not report significant differences. We also did not find significant differences for the dimensions assessed by the two graders (subjective measures).

Cognitive and Affective Load

In order to study the cognitive and affective implications of time and space in CIS, we relied on self-assessment. A comparison of teams across conditions using ANOVA revealed that working asynchronously (C4ASYNC) helped team members to diminish their cognitive load, when compared to teams working in C12F, F(3,76)=2.931, p<0.05. We also found that teams working remotely located with audio support (C3AUDIO+TEXT) experienced less affective load than teams in C12F, F(3,76)=3.128, p<0.05 (Table 6).

Table 6. Means and standard deviation for cognitive and affective loads in each condition. Arrows indicate that significant differences were found for the corresponding measure, being ↑ for significantly higher and ↓ for significantly lower.

<table>
<thead>
<tr>
<th></th>
<th>C12F mean (s.d.)</th>
<th>C2TEXT mean (s.d.)</th>
<th>C3AUDIO+TEXT mean (s.d.)</th>
<th>C4ASYNC mean (s.d.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL</td>
<td>14.50 (2.93) ↑</td>
<td>12.75 (3.21) ↑</td>
<td>12.00 (2.36) ↑</td>
<td>11.65 (4.42) ↓</td>
</tr>
<tr>
<td>AL</td>
<td>84.70 (40.20) ↑</td>
<td>61.95 (26.16) ↑</td>
<td>57.30 (19.97) ↓</td>
<td>65.00 (31.99) ↓</td>
</tr>
</tbody>
</table>

DISCUSSION

The analyses and results presented above suggest that time, space, and also the richness of the communication channel have different implications on the search practices as well as on the experience of users that engage in a CIS task. We revisit our research questions and address them based on the results described in the previous section.

Our first questions asked how collaboration in different time and space conditions could affect teams’ interactions within a CIS task. Communication analyses suggest that teams working synchronously at the same location (C12F) spend more time coordinating and defining strategies than participants working remotely located with a restricted communication channel (C2TEXT). This is also consistent with the results that show that the communication effort (E) of teams in C12F was significantly higher than that in C2TEXT. We argue that being at the same place and having the possibility to interact F2F, facilitates the exchange of messages between team members. A negative implication for team members of being aware of the physical presence of their partners in a shared space is the promotion of social interactions that in some cases may be unrelated to the task being performed (NT). This may become a distraction for the effective execution of the task.
At a more general level, channels with audio support seem to unbalance the intervention of team members. This means that one of the members of a given team may tend to overuse the communication channel sending more messages to his/her partner in a bidirectional communication. Under certain circumstances this can be positive (for example, reducing affective and cognitive load), however, when communication becomes more natural (like in C1(TEXT)), this overuse may become a negative factor to the team.

Conditions with restricted communication either because of time (C4_{ASYNCH}) or because of specific constraints of the channel (C2_{TEXT}) tend to be more task-oriented, which means that the communication effort of team members focuses mainly on the problem being solved.

Our second research question addressed how collaboration in different time and space conditions could affect the productivity of teams within a CIS task. Results in this regard indicate that working at the same place and even at the same time, with an active communication channel may reduce the likelihood of team members to formulate different queries. We believe that the intentional exchange of messages as well as the unintentional ones could bias team members’ definition of queries, thus limiting the possibility to be exposed to diverse information sources and diverge their information search practices. By formulating similar queries, team members tend to overlap in their information coverage. In this sense, if the goal is to explore different information sources, time and space overlap should be reduced. In our study, such a condition is represented by C4_{ASYNCH}.

On the other hand, if the goal is to improve the effectiveness of the search process by covering more useful information, diversity should be reduced so that team members can focus in the exploration and sense making of a specific area of the search space. Based on our results, a condition that offers appropriate conditions for diversity and useful coverage is C3_{AUDIO+AUDIO}.

Our third question was concerned with the effects of different time and space conditions, if any, on information synthesis within a CIS task. For the particular task in this study, results suggest that regardless of the conditions of time and space that govern the collaborative search process, teams evaluate, make sense, organize, and use the information collected during their information search process in a similar way.

Finally, the fourth research question asked how different time and space conditions could affect cognitive and affective loads of teams within a CIS task. Our results suggest that working at the same location and in parallel (C1(TEXT)) would be a negative factor for the cognitive and affective load of team members. We believe that such implications are related to communication factors and social presence, as discussed in RQ1. Although F2F communication facilitates the exchange of messages, unbalanced communication, messages that are unrelated to the task being performed and the effort required to communicate, would contribute negatively to the experience of users. For example, team members working at the same place would need special coping skills to deal with constant interruptions, distractions, pressure, and the task itself, among other factors that increase their cognitive and affective load, and thus affect their productivity.

**CONCLUSIONS**

In this paper we investigated the implications of different conditions of time and space in CIS. Our results showed differences at the level of communication practices, productivity, as well as the cognitive and affective experience of team members.

We note that the differences identified should not be interpreted directly as positive or negative, but rather within the context of task and requirements in which they occur. According to our findings, there are no major differences in terms of productivity; however, there are differences during the process in which participants engage to accomplish a CIS task. For instance, audio-based communication seems to encourage communication, which may result in positive implications at early stages of the search process, where team members discuss approaches to tackle the search task. As the process goes further, active communication as well as social presence seem to increase affective and cognitive load, thus becoming an intervening factor for effective collaboration. In these stages, our results suggest that more passive communication or reducing social presence by working at different locations (C2_{TEXT} and C3_{AUDIO+TEXT}) could help team members to discover more diverse and useful information and also to reduce their levels of affective and cognitive load.

We believe that this closer look at communication processes and the implication of time and space in CIS will help in two major ways: First, by providing new insights about how information seeking occurs in intentional and explicit collaborative situations, helping to establish theoretical foundations for studying and evaluating time and space factors in CIS; and second, by enabling system designers to provide appropriate and contextual support in a CIS system depending upon factors such as the stage of the search process, the conditions of work in terms of time and space, and the communication channels available.

As part of our future work we will investigate additional communication channels such as video and email, with the aim of having a more complete view of the implications of different communication channels, as well as time and space conditions in CIS.

**REFERENCES**
