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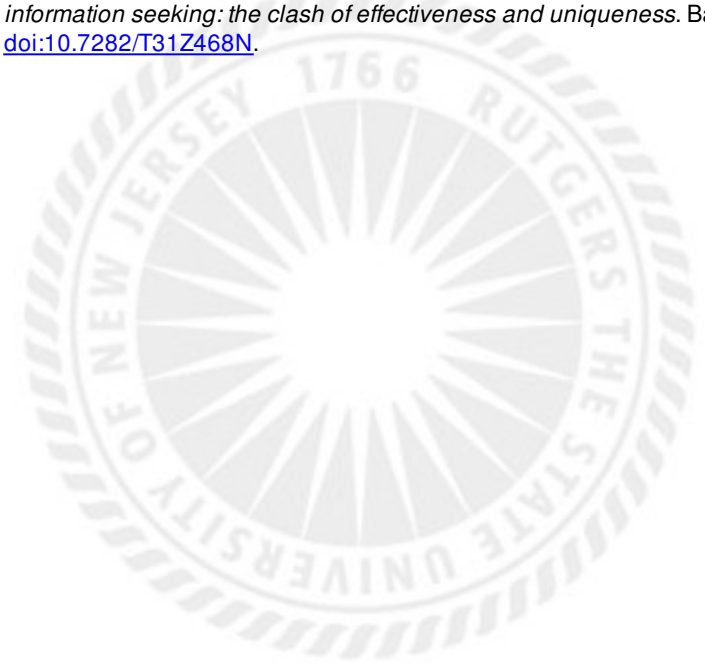

Time and Space in Collaborative Information Seeking: The Clash of Effectiveness and Uniqueness

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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 (Twidale 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

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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).

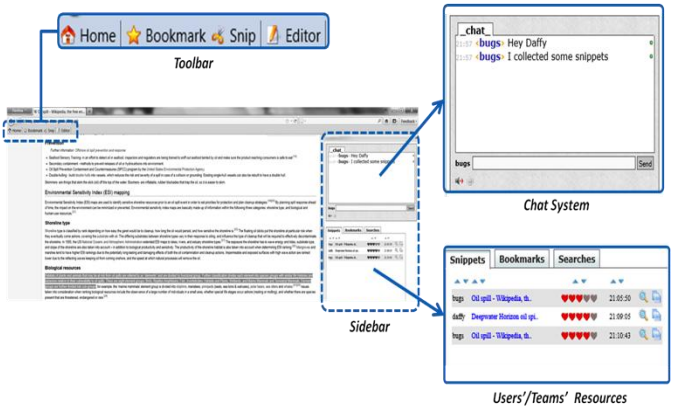

Figure 1: A snapshot of the experimental system with parts of it shown in details.

On the other hand, the sidebar gives access to a communication channel (for this study, it was text and audio depending upon the collaboration condition) and to the information collected as well as the search and browsing history of all users within a team.

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 1: Summary of session stages.

Stage	Description	Time (min)
1	Participants were introduced to the study and asked to sign a consent form.	3
2	Participants watched a brief tutorial in order to learn the basic functionalities required during the task.	3
3	Participants individually filled out a set of pre-task questionnaires.	4
4	Participants read the task description (presented later).	3
5	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.	30
6	Participants filled out post-task questionnaires.	6

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:

$C1_{F2F}$: Two participants co-located with different computers and face-to-face communication.

$C2_{TEXT}$: Two participants at different rooms with text-based communication.

$C3_{AUDIO+TEXT}$: Two participants at different rooms with audio and text-based communication.

$C4_{ASYNCH}$: Two participants working at different times.

In conditions $C2_{TEXT}$ and $C3_{AUDIO+TEXT}$, participants were located at different rooms, without direct visual or auditory contact, thus being able to communicate only through the specific communication channels enabled in the respective conditions. Pairs in the first three conditions (synchronous conditions) were given 30 minutes to work in parallel in the task described in the previous section. On the other hand, teams in the asynchronous condition ($C4_{ASYNCH}$) had to perform the same task as the other three conditions while working sequentially during 25 minutes each. For this specific condition, however, we defined a different procedure to compensate the time and effort of synchronous conditions. This procedure is described as follow.

First, each team was given a total of 5 minutes at the beginning so that both team members could read the task and define a strategy in a brief face-to-face meeting (F2F).

Second, based on the decision made by team members, one of them (Participant B) had to leave the laboratory and wait outside for his/her partner to complete his/her part of the task.

Third, in the following 25 minutes, the team member who remained in the laboratory (Participant A) proceeded according to the decisions made in the initial meeting. In addition, he/she had the possibility to use the chat system to leave text messages for his/her partner. During this time the participant waiting outside the laboratory (Participant B) did not have access to technology nor to any information source, in order to avoid the possibility of engaging in synchronous work.

Fourth, after the 25 minutes, both participants were given additional 5 minutes to briefly meet in the lab so that they could talk and discuss about what was done and what needed to be done.

Finally, in the following 25 minutes, Participant B proceeded accordingly to the decisions made in the second meeting. On the other hand, the participant waiting outside the laboratory (this time Participant A) was not allowed to help his/her partner, thus eliminating the possibility of synchronous work.

As a result, at the end of the session each team in all the conditions was given a total of 60 minutes for actual work (30 minutes when working in parallel or 60 minutes for sequential work).

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.

Code	Description	Examples
Task Coordination (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.
Task Content (TN)	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
Task Social (TS)	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.
Non-Task Related (NT)	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?
Non Codable (NC)	Statements that do not belong to any of the above categories	1. What happened?

Data Pre-Processing

In order to perform analyses of the data collected, we performed cleaning, segmentation, and synchronization procedures for the data of each participant. Overall we captured approximately 40 hours of audiovisual material and thousands of records containing information about users' actions while working in the Web browser. Because of our communication analyses focused on the task stage (Table 1: Stage 5), we first proceeded with the segmentation of the audiovisual data of each user in order to identify and mark the areas in which participants were performing the task; we used for this segmentation videos containing the desktop activity for each user. Following, we synchronized this segmented data with the data logs recorded by Coagmento. Finally, for each team we extracted the specific segments of audio and text data containing the communication among team member; as a result we ended up with approximately 12 hours of audio communication for $C1_{F2F}$, $C3_{AUDIO+TEXT}$, and $C4_{ASYNCH}$; and 263 text messages for $C2_{TEXT}$. Although text channel was activated for all conditions, no text messages were found for those in $C1_{F2F}$, $C3_{AUDIO+TEXT}$, nor $C4_{ASYNCH}$. From all 40 teams, we discarded the audio communication data of one team due to the file containing the recording was corrupted.

Coding

Using an adapted version of Strijbos et al. (2004) coding scheme, two coders analyzed the audio-based as well as the text-based communication among team members. We considered full sentences or part of them as unit of analyses and they were coded under the categories described in Table 2.

In addition to the categories of Table 2, messages were also coded if they were Questions (Q) or Answers to those questions (A). For instance, from the examples provided in Table 2, "How do you want to do this?" in addition to be coded as Task Coordination (TC), it was also coded as Question (Q).

Overall more than 4,000 messages, including audio and text, were coded. The inter-rater reliability between the two coders was found to be Kappa=0.799 ($p<0.01$).

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).

$$V = \#messages \quad (1)$$

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 ($C1_{F2F}$, $C3_{AUDIO+TEXT}$, and $C4_{ASYNCH}$), we subtracted the ending time and the starting time of each message (Eq. 2). For the condition with text-based communication ($C2_{TEXT}$), 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).

$$E_{Audio} = \sum (end(msg) - start(msg)) \qquad (2)$$

$$E_{Text} = \sum \left(\frac{\#words(msg) * 60}{50} \right) \qquad (3)$$

Balance (B): 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.

$$B_V = \left| V(P_A) - V(P_B) \right| \qquad (4)$$

$$B_E = \left| E(P_A) - E(P_B) \right| \qquad (5)$$

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 3. Productivity measures.

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

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 (F-K) 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 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*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 $C1_{F2F}$ was significantly higher than in $C2_{TEXT}$, $F(3,35)=4.431$, $p<0.01$. In terms of task content (TN), it was found that $C2_{TEXT}$ 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 $C1_{F2F}$ were more likely to talk about topics outside of the context of task than teams in $C2_{TEXT}$ and $C4_{ASYNCH}$, $F(3,35)=6.930$, $p<0.01$. Figure 2 and 3 summarize the communication of teams in each condition.

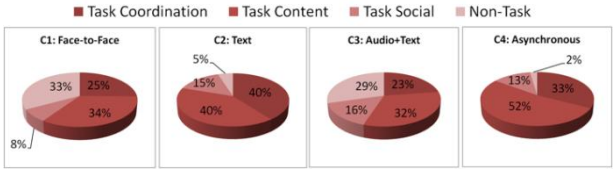

Figure 2: Proportions of communication in terms of the type of messages exchanged per condition.

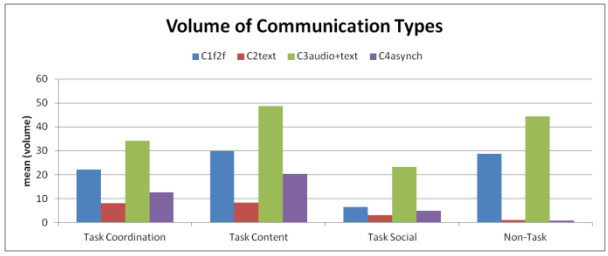

Figure 3: Comparison of volume of communication types across condition.

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 ($C1_{F2F}$) had greater exchange of messages than teams in $C2_{TEXT}$ and $C4_{ASYNCH}$, $F(3,35)=10.536$, $p<0.01$ (Figure 4). Similar was the case for teams in $C3_{AUDIO+TEXT}$, who exchanged significantly more messages than those in $C2_{TEXT}$ and $C4_{ASYNCH}$ ($p<0.05$).

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 $C1_{F2F}$ was greater than that in $C2_{TEXT}$, $F(3,35)=7.482$, $p<0.01$, and that in $C4_{ASYNCH}$ ($p<0.05$). It was also found that the communication effort of teams in $C3_{AUDIO+TEXT}$ was greater than that in $C2_{TEXT}$ ($p<0.05$).

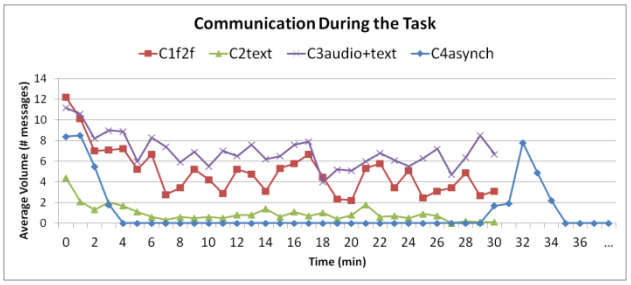

Figure 4: Average communication volume in each minute during the task.

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 Be* must be interpreted in the opposite direction: Lower values mean more balance.

	$C1_{F2F}$ mean (s.d.)	$C2_{TEXT}$ mean (s.d.)	$C3_{AUDIO+TEXT}$ mean (s.d.)	$C4_{ASYNCH}$ mean (s.d.)
TC	22.11 (11.95) ↑	8.00 (4.37) ↓	34.20 (30.62)	12.70 (9.35)
TN	29.89 (18.17) ↑	8.20 (5.14) ↓	48.80 (35.63) ↑	20.40 (10.65) ↑
TS	6.56 (4.36)	3.00 (3.16)	23.30 (28.55)	4.90 (5.32)
NT	28.78 (14.67) ↑	1.00 (1.63) ↓	44.30 (48.75)	0.90 (2.23) ↓
V	150.22 (39.44) ↑	28.80 (18.35) ↓	209.00 (158.97) ↑	43.10 (20.62) ↓
E	390.55 (125.98) ↑	185.16 (106.07) ↓	636.00 (424.41)	219.60 (69.82)
B_V*	40.00 (9.04) ↓	13.00 (8.14) ↑	38.80 (27.10) ↓	8.10 (4.84) ↑
B_E*	155.11 (51.06)	111.24 (47.13)	200.50 (107.20) ↓	84.80 (65.31) ↑
Q	27.33 (9.5) ↑	4.5 (2.92) ↓	34.20 (23.07) ↑	10.10 (6.40) ↓
A	19.78 (8.80) ↑	2.3 (1.95) ↓	23.50 (15.64) ↑	6.90 (3.84) ↓ ↑

A comparison of communication balance in terms of the number of messages exchanged (B_V) indicates that teams in $C2_{TEXT}$ and $C4_{ASYNCH}$ achieved greater balance than those in $C1_{F2F}$, $F(3,35)=11.881$, $p<0.01$. It was also found that teams in $C4_{ASYNCH}$ had better balance than those in $C3_{AUDIO+TEXT}$ ($p<0.05$).

Similarly, an analysis of balance in terms of the communication effort (B_E), revealed that teams in $C4_{ASYNCH}$ had significantly better balance than teams in $C3_{AUDIO+TEXT}$, $F(3,35)=4.928$ ($p<0.05$). 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 $C1_{F2F}$ issued

more questions than those in $C2_{TEXT}$ and $C4_{ASYNCH}$, F(3,35)=11.415, *p<0.01*. In a similar way, participants in $C3_{AUDIO+TEXT}$ issued more questions than those working in $C2_{TEXT}$ and $C4_{ASYNCH}$ (*p<0.05*).

Consistently, the number of answers of teams in $C1_{F2F}$ was higher than that of teams in $C2_{TEXT}$ and $C4_{ASYNCH}$. Likewise, team members in $C3_{AUDIO+TEXT}$ responded more questions than those in $C2_{TEXT}$, F(3,35)=11.845, *p<0.01*. At *p<0.05*, participants in $C3_{AUDIO+TEXT}$ provided more answers than those in $C4_{ASYNCH}$; and those in $C4_{ASYNCH}$ responded more questions than those in $C2_{TEXT}$.

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.

	$C1_{F2F}$ mean (s.d.)	$C2_{TEXT}$ mean (s.d.)	$C3_{AUDIO+TEXT}$ mean (s.d.)	$C4_{ASYNCH}$ mean (s.d.)
UI	19.00 (5.01)	17.50 (5.06)	22.40 (5.82) ↑	15.40 (5.45) ↓
QD	19.69 (8.86) ↓	23.13 (8.47) ↓↑	22.29 (8.87) ↓↑	27.40 (17.01) ↑

First of all, teams working in $C3_{AUDIO+TEXT}$ were able to cover significantly more useful information (UI) than those in $C4_{ASYNCH}$, 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 ($C1_{F2F}$) 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 ($C4_{ASYNCH}$), 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 $C4_{ASYNCH}$ 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 ($C4_{ASYNCH}$) helped team members to diminish their cognitive load, when compared to teams working in $C1_{F2F}$, F(3,76)=2.931, *p<0.05*. We also found that teams working remotely located with audio support ($C3_{AUDIO+TEXT}$) experienced less affective load than teams in $C1_{F2F}$, 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.

	$C1_{F2F}$ mean (s.d.)	$C2_{TEXT}$ mean (s.d.)	$C3_{AUDIO+TEXT}$ mean (s.d.)	$C4_{ASYNCH}$ mean (s.d.)
CL	14.50 (2.93) ↑	12.75 (3.21)	12.00 (2.36)	11.65 (4.42) ↓
AL	84.70 (40.20) ↑	61.95 (26.16)	57.30 (19.97) ↓	65.00 (31.99)

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 ($C1_{F2F}$) spend more time coordinating and defining strategies than participants working remotely located with a restricted communication channel ($C2_{TEXT}$). This is also consistent with the results that show that the communication effort (E) of teams in $C1_{F2F}$ was significantly higher than that in $C2_{TEXT}$. 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 $C1_{F2F}$), 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 ($C1_{F2F}$) 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.

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