Study of the effect of awareness on synchronous collaborative problem-solving

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Abstract—**In this article we present a study of phenomena of attention shifting and awareness that occur during a synchronous collaborative activity. The objective of this research is to analyze the interplay between task, attention mechanisms and the dynamics of collaboration. This study presents the detailed examination of attention shifting of a user engaged in a collaborative activity. It also discusses possible reasons for unattended events and awareness failures. The findings of this analysis can provide useful information for the design of groupware awareness mechanisms as well as for the evaluation of groupware applications.**

Keywords-component; collaboration; awareness; attention; eye-tracker

I. Introduction

The importance of awareness in collaborative systems has been the object of many studies. Research has been conducted on the mechanisms that a groupware system should include, in order to support its users [9], [18] and on methods for evaluation of awareness support [10]. However, most design and evaluation methodologies for collaborative applications do not consider eye gaze [5] and eye movements, which are closely related to attention mechanisms [19].

The idea of this research is to study how eye movements/gaze of group members relate with awareness. This is studied in the context of an educational, collaborative activity that involves distant partners engaged in synchronous communication and problem solving. The objective is to unveil the factors that affect a collaborator's behavior and the quality of collaboration. We believe that these factors can be proved useful for designing and evaluation of groupware applications.

It has been proposed that awareness mechanisms have to be adaptive and closely related to the task's nature [20], however users' cognitive workload should also be taken into consideration. With this in mind, a study was conducted in which the gathered eye-tracking data were analyzed with respect to the user's cognitive workload, i.e. we examined user response to visual stimuli coming from shared resources of a collaborative environment and related this behavior to the user cognitive workload. The objective of this research is to gain better understanding of the patterns of observed behavior in order to propose future awareness mechanisms that will assist users to maintain knowledge about the shared workspace, without taking the focus away from their activity.

The paper presents a brief overview of the factors that affect quality of collaboration and an overview of the conducted research related to awareness support (section II). Then we present the experimental setup of our study and the analysis of the phenomena that emerge during collaborative activities (section III and IV). Finally, we include a discussion about our main findings (section V).

II. Aspects of Collaboration and the importance of Awareness

Computer mediated synchronous collaboration, especially when intended for learning, is a complex to analyze and model activity, since it depends on many factors. Various studies have been conducted on the factors that influence the quality of collaboration, on how to foster successful collaboration and assess its quality [15]. For this purpose theoretical models and rating schemes have been developed [15], [13]. Collaboration is strongly related to communication, joint information processing, coordination, relation management and motivation. However, most of the aforementioned aspects are affected by the collaborative application used [18], [6], [2].

Collaborative applications, usually, provide a shared workspace, that is perceived as a blackboard, and a chat tool to facilitate communication. Research has shown that in order to achieve successful, synchronous collaboration, users have to maintain knowledge, both, about the interaction with other participants and the status of the shared resources [12]. A common way of providing awareness, found in many such applications, is to notify users on special events; e.g. when a chat message arrives from a distant partner, or when a common object that appears on the workspace, has been edited. This notification may take the form of a distinct visual or audible signal [10], [11].

III. Experimental Setup

For the purpose of this paper, a study was conducted. Six students of an undergraduate Computer Science course were grouped in dyads and were given the task to evaluate a website by applying the Cognitive Walkthrough (CW) method [22]. The partners of each dyad had to collaborate synchronously, using the groupware application Synergo [3]. The collaborators had to browse through the site under evaluation, in order to carry out a specific task. At each step of the process they reflected using typical questions that relate to the feedback they received and the next appropriate action to do, as imposed by the CW evaluation method. More specifically, the evaluators had to visit the website of an airport and carry out the following task: "*You are traveling by air from X to Y. You are landing at Airport Z and you would like to rent a car to drive to a certain destination. Use the official website of the airport – a link of the website was provided - to find out which car rental companies currently operate at the Airport Z*". Then, students had to use the groupware application in order to develop a state diagram, depicting the process. On this diagram usability evaluation remarks were associated, based on the aforementioned questions for every step of the process.

This task necessitates shifting of attention between various objects. The users had to interact with the browser and navigate through the airport website, to use the chat tool of Synergo in order to communicate with their partner and to act in the Synergo common workspace in which they had to build the diagrammatic representation ("Fig. 1"). This division of attention among multiple areas, portrays a realistic collaborative session and rich patterns of attention related behavior are expected to emerge.

The duration of the collaborative task was around 20 minutes. During the collaborative sessions the eye gaze of one collaborator from each dyad was recorded using a Tobii T60 eye-tracker [21] (Table I).

The groupware application (Synergo) that facilitated collaboration provides a common workspace and a chat facility ("Fig. 2"). In the common workspace the collaborators developed the requested state diagram and used the chat area to exchange text messages. All the actions, both in the workspace and in the chat area, were instantly broadcasted and visible to the other collaborator. Synergo provides limited support for awareness. In case a user edits the textual content of an object on the common workspace, an avatar appears on the top, left corner of the object indicating that a change is taking place. This color of the avatar indicates the identity of the user who edits the object ("Fig. 3"). Additionally, all these actions were recorded to a logfile with details on the time the action was performed, the type of the action, the user involved and other parameters such as content (e.g. in a text message), location on the workspace (e.g. when inserting a note).

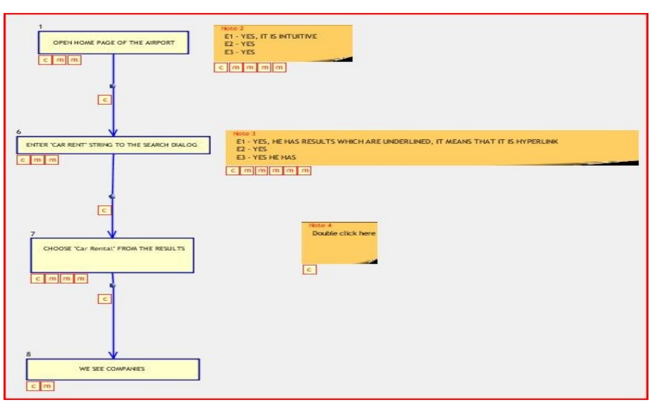

Figure 1. Example of state diagram

TABLE I. USER DYADS

Dyads	User monitored by eye tracker	User
Session A	User A	User A'
Session B	User B	User B'
Session C	User C	User C'

In this study we are mostly focused on actions on shared resources that have a visual effect, not only for the actor but the other collaborators as well. In this sense, we classified all the actions and their possible visual effect. In detail:

- *Chat message (CHM):* text message written and posted in the chat area. Concerning the visual effect that is created, chat messages are categorized as long size messages and short size messages.
- *Insert Object (INO):* creation and insertion of an object on the common workspace. The significance of this action and visual effect depends on whether the new object is inserted in a visible area or a non-visible area of the common workspace.
- *Delete Object (DLO):* the action of deleting an existing object. As with inserting objects (INOs), the visual effect of deleting an object depends on whether this object was placed in a visible or not area of the workspace. Moreover the visual effect depends on the dimensions of the object.
- *Modify Text (MDT):* inserting or changing the textual content of an object that already exists on the workspace. This event may concern a textual context which is being edited or new text inserted.
- *Paste Object (PSO):* the insertion of an object in the workspace by copying and pasting an existing object. The visual effect of pasting is quite similar to that of inserting an object. A special case is pasting multiple objects at once.

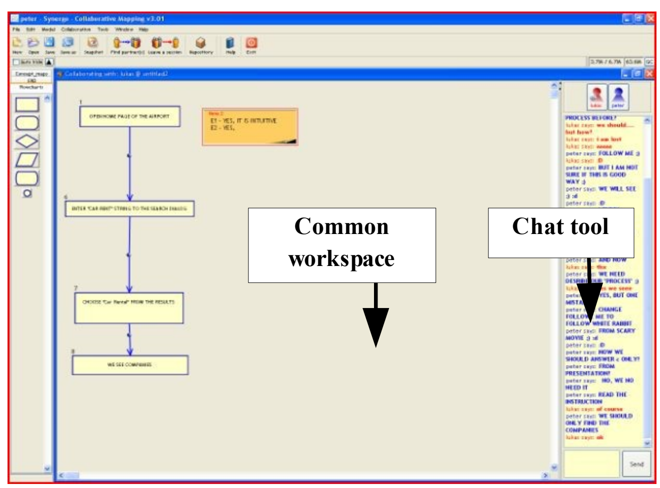

Figure 2. Synergo Collaborative environment

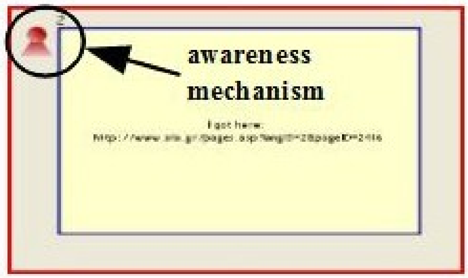

Figure 3. Color coded avatar identifying editing activity of a partner

- *Resize Object(RZO):* the modification of the size of an existing object on the workspace. The effect on awareness is dual and related to whether the modifications take place in a visible or a non-visible area of the workspace and the size of the new object versus the old one.
- *Move Object(MVO):* the action of moving an existing object to another position in the workspace. The visual effect of this action differs depending on whether the object is moved from or to a visible or not, area of the workspace. Additionally, the size of the moved object has, also, an impact on awareness.

IV. Analysis of the awareness phenomena in collaborative sessions

In this section the analysis of the collaborative sessions is presented. Our focus is to understand how lack of awareness mechanisms in relation to user's cognitive workload affects the collaborative activity.

A. Sessions' Analysis

1) Session I: UserA – UserA'

At the first session (userA-userA') both collaborators had the same background, they collaborated smoothly and their results were of good quality. They used the common workspace and the chat tool equally. In total they conducted 97 actions, 46 of them were chat messages (Table III). This dyad spent 10' minutes (out of 20') for browsing the suggested by the task, website. The rest of the time was spent on building the needed state diagram.

In the beginning of the session the users mostly exchanged chat messages and explored the collaborative tool. In the initial chat messages the collaborators decided their common plan of action. During the exchange of these messages, they were focused on the chat tool and therefore read and replied promptly, with minimum delay. In general, these minimum delays were mainly due to user's cognitive load (the needed cognitive effort to answer a question), or due to the fact that, sometimes, a user looks at the keyboard when composes text and fails to notice an incoming message. Once the collaborators decided their plan of action they focused on the workspace and used the chat tool just to ask questions.

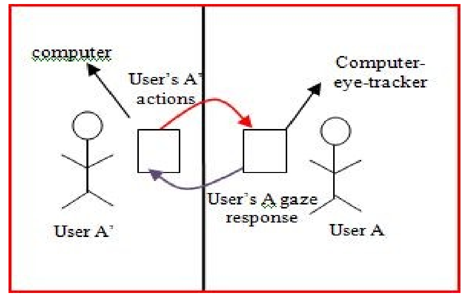

Figure 4. Collaboration Setting for Session A

Concerning the activity, users divided both the task and the workspace and each one has undertaken his part. As a result, each collaborator was devoted on his task and focused on his part of the common workspace. Since, Synergo has no built-in awareness mechanisms, the reasons for causing shift of attention are mainly, the workload of the user (high workload forces a user to stay focused on his task) and visual changes on the common workspace. In this session User A who was monitored by the eye-tracker, gazed only at the objects that he created or edited. When he was finishing a set of actions, thus had a break in his cognitive process, he was examining User's A' activity on the workspace or the chat area (9 instances). During these occasions he was editing User's A' objects (3 instances) or read/wrote on the chat area (5 instances).

Since both collaborators chose to divide the task and focus on their part, awareness failures began to occur. User A missed both text messages and actions on the workspace and that had a significant impact on the quality of collaboration. In order to assess the quality of collaboration someone may examine how soon users reply to a chat message. A delay can be perceived as lack of interest or unwillingness to collaborate [13]. In "Fig. 7" we can view the eye-gaze activity of User A regarding the actions of his collaborator that have a visual effect. These actions are performed on the workspace and chat area. The upper line represents the eye gaze of User A and the bottom line represents the workspace and chat activity of User A'. The lines that connect both activities represent the gaze response of User A to an action of User A'. The shortest the line is, the quickest the eye response; indicating the time that the user needed to realize his collaborator's actions. The shaded areas in the gaze response line represent the time periods that User A was engaged in a particular task and therefore, had a high workload.

During the first minutes of the activity there are no significant delays, neither in the workspace, nor in the chat. By studying the eye gaze of User A we confirmed that he responded to visual changes of the shared resources within short time periods. As the activity unfolds, there are bigger delays. These delays coincided, in most of the cases, with the periods that User A has a cognitive workload. At the last part of the activity we observed that gaze response delays had increased. Especially for the chat area they reached up to 3' minutes.

2) Session II: User B – User B'.

At the second session users had not the same background, as User B' was more experienced in website evaluation methodologies such as cognitive walkthrough. In total, they conducted 128 actions, 65 were chat messages (Table III).

At the beginning both users exchanged messages concerning the task. For the first 5' minutes there was an intense chat activity, without delays, because both users were concentrated in the chat area. Then, they adopted a different strategy than the previous dyad, mainly because User B' was an expert on the evaluation domain; User B' carried all the work on the workspace. User B tried to monitor everything and understand what his collaborator is doing, mostly by posing questions . Additionally, User B asked for help on how to use Synergo (4 instances). User's B lack of understanding resulted in deletions of certain objects (3 instances) created by the other user, because he couldn't understand their impact on the activity. User B kept deleting objects until he was notified not to do so, through the chat tool. A significant event in this session was when User B stated that "*I am deleting objects because I am trying to find out how Synergo works*". This shows not only confusion but bad coordination between them.

The second session was poor in terms of collaborative activity, since one of two users was unable to follow his collaborator's progress. User B mostly used the chat area in order to communicate with his collaborator, but had no actual role in the workspace. Since he had no intense activity, he was able to follow the chat and workspace changes and in this sense he was aware of his collaborator's actions ("Fig. 8"). However the lack of awareness mechanisms that could clearly inform him of certain events on the working space led him to misunderstandings.

3) Session III: User C – User C'.

At the third session users shared the same background. They spent 12' minutes in browsing the website and 8' minutes using the collaborative application. In total 81 actions were performed, 36 of them chat messages (Table III).

At the beginning of this session the collaborators decided to work on the same objects and to progress together in reaching the solution. But as they proceeded, they failed to coordinate. User C took the initiative and User C' kept asking for help, which was not provided in time since User C was focused on the workspace and failed to see the chat messages. This led to loss of communication and coordination, as User C was even more immersed to his actions and this pattern continued until the end of the session, resulting in a failure in collaboration but a satisfactory solution on the task level ("Fig. 9").

TABLE II. AVERAGE RESPONSE TIMES

	User A	User B	User C
avg_res_workspace	00:01:00	00:00:53	00:00:20
avg_res_chat	00:01:01	00:00:10	00:00:39
avg_res_total	00:01:00	00:00:36	00:00:27

TABLE III. SESSION A: ACTIONS STATISTICS

Session	**Session A**		**Session B**		**Session C**	
Actor	**User A**	**User A'**	**User B**	**User B'**	**User C**	**User C'**
Actions	28 (54%)	23 (46%)	17 (26%)	46 (74%)	31 (71%)	13 (29%)
Messages	19 (41%)	27 (59%)	35 (53%)	30 (47%)	22 (62%)	14 (38%)

V. DISCUSSION

In order to validate the study we estimated the average response time to visual changes on shared resources. Response time is defined as the time difference between the time an action took place until the time the collaborator realized that action. In table II we present the average response times for workspace changes (avg_res_workspace), changes in the chat area (avg_res_chat) and in total (avg_res_total), for the three users who were monitored.

From table II it is evident that all three sessions have different collaborative characteristics. At the first session the collaborators divide the task (equal number of workspace actions) and they work individually. This results in big delays regarding gaze response (00:01:00). At the second session one of the users tries to reach the solution and his collaborator monitors every action. Thus the user that monitors all the actions (User B) and is monitored by the eye-tracker, has a small response time. Additionally, we have to clarify that User's B response time is not the smallest one since he tries to understand what is going on, and has an increased cognitive load. The smallest response time is reported at session C from User C, because he is the one working towards the solution and his collaborator is not engaged in the task (13 actions).

From the above analysis it is evident that a collaboration tool should have an adaptive awareness mechanism. This mechanism has to take into consideration not only the changes on the shared resources, but the cognitive workload of the users as well as the content of the users' actions. When a user is immersed into an activity (high cognitive load) he is in greater need for awareness support. For example, user X is editing objects in the workspace. A possible awareness mechanism can be a green visual effect that turns to red as time goes by and no response is provided. Regarding content (for example chat messages) a possible awareness mechanism is a blinking effect when a question is posted in the chat area. Another significant finding is that awareness mechanisms are mostly useful to users who have the motive and the tendency to collaborate. For the other cases, such as session C, we believe that awareness support will make no significant difference.

For the rest of the section we will attempt to analyze the aforementioned findings, taking into consideration Norman's Seven Stages of User Activity theory [17], and by presenting two examples, one for each finding. According to this theory, user activity can be analyzed in seven cognitive stages, which can be grouped into three general categories: Goal Formation, Action, Interpretation. Activities though, cannot be described as a serial transition from stage to stage, on the contrary, some stages may be skipped, repeated or appear out of order. This analysis in seven stages varies depending not only on the task's nature and user's intention, but also on external stimuli that may occur. In a collaborative activity such stimuli may be incoming chat messages and changes in the common workspace. In Norman's theory Goal Formation and Interpretation is an individual's concern and have no effect on collaborating parties [14]. Acting however, may have visual effects on a shared resource and therefore can be realized by other users.

"Fig. 5" depicts an example. In session A, User A' creates a part of a state diagram and User A creates another part of the same diagram in a different location on the workspace. User A' faces a problem in connecting two objects and he submits a question asking for help (19:32:21). User A, according to Norman's theory, has already established a goal (the creation of the state diagram) and is working for its completion. He moves among the rest stages of this activity very quickly. In a few words, he specifies an action sequence; he executes an action; he perceives and interprets system's state; he moves on to the next action and at some point evaluates the result. During this process he checks the chat area and composes a reply to help his collaborator (19:33:44). However, because he is dedicated to his goal, which is not fulfilled yet, he focuses to the workspace without sending the message. Meanwhile, User A' sends another message. That event reminds User A of the text message that he has composed but never sent and he replies with instructions. This lack of awareness, not only costs two minutes time, which is rather significant for a twenty minutes activity, but also interfered in both users' activities more than one time.

In "Fig. 6" are presented the series of actions of User B and User B' for a time period of two minutes and a half. During this time User B' is creating the required state diagram and User B takes no significant to the task activity, except composing chat messages. He is confused about the task's objective and asks for help. User B begins editing on the workspace after receiving a chat message with instructions. He inserts an object (19:00:52), then reflects on his actions and decides to delete it. He is confused about the activity and that is also confirmed from the fact that he deletes User's B' objects for no obvious reason. This pattern is repeated for two more times. According to Norman's theory, user B is "captive" between the two first stages of the activity, thus is unable to establish the goal and form the intention. Apparently, User B was under pressure, he could not plan his actions and when he saw new objects emerging on the workspace he believed that they were "junk" and, constantly, tried to delete them without realizing that they were created by his collaborator.

User A'	timeline	User A
Chat message	19:32:21	
	.....	
	.....	
	.....	
Chat message	19:33:34	*checks chat*
	.....	*composes reply*
	.....	*forgets to send chat message*
	.....	
	19:33:52	*views new message*
	.....	
	.....	
	.....	
Chat message	19:34:01	*posts the reply composed earlier*

Figure 5. Session A: sequence of actions

User B'	timeline	User B
Insert Entity	18:59:59	
	.....	
	.....	
	.....	
	19:00:52	Insert entity
	.....	
	.....	
	.....	
	19:01:41	Delete object
	.....	*user confused*
	.....	*erases other user's object*
	.....	
	19:01:45	Delete object
Insert Entity	19:01:52	
	.....	
	.....	
	.....	
	19:01:56	Delete object

Figure 6. Session B: sequence of actions

VI. Conclusions

Collaboration activities are difficult to model and analyze, especially when aiming to learning purposes. The outcome of a collaborative activity depends on the quality of collaboration itself, in particular partners' motivation and attitude towards collaboration, as well as, on the tools that mediate the activity. The notion of awareness is of great importance in computer mediated collaborative activities. Without proper awareness mechanisms, communication breakdowns may occur and collaboration may not unfold smoothly.

Our intention was to find out whether certain behaviors, such as not responding to text messages or not becoming aware of conflicts on the workspace, were due to lack of motivation or lack of adequate awareness mechanism. Moreover we focused on the role of cognitive workload and its relation to awareness.

Our results, show that users with a high cognitive workload that are focused mainly on their own task, remain unaware of their collaborators' actions or simply ignore them, since these actions are not, directly related to their own goal. This situation to their collaborators becoming disappointed, frustrated and gradually losing interest. On the other hand, users with low activity are more responsive to incoming events and shift attention to them. Therefore, we believe that awareness mechanisms should not just attract user's attention on specific events, but they should also vary according to the nature of the task and the workload of the collaborators.

In further research we intend to design and implement adaptive awareness mechanisms, integrate them in collaborative applications and conduct studies to determine how the characteristics of the awareness mechanisms, such as the kind and intensity of awareness signal, affect the collaborative activity.

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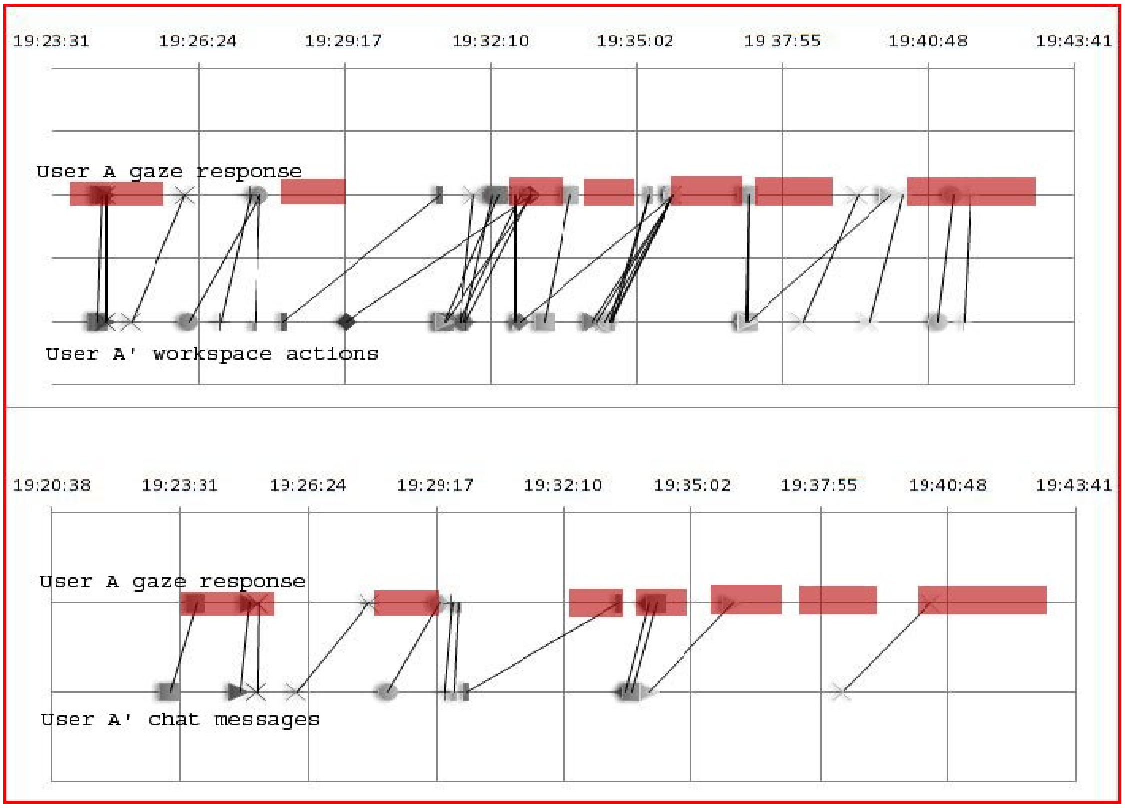

Figure 7. Gaze activity of User A regarding User's A' workspace and chat events

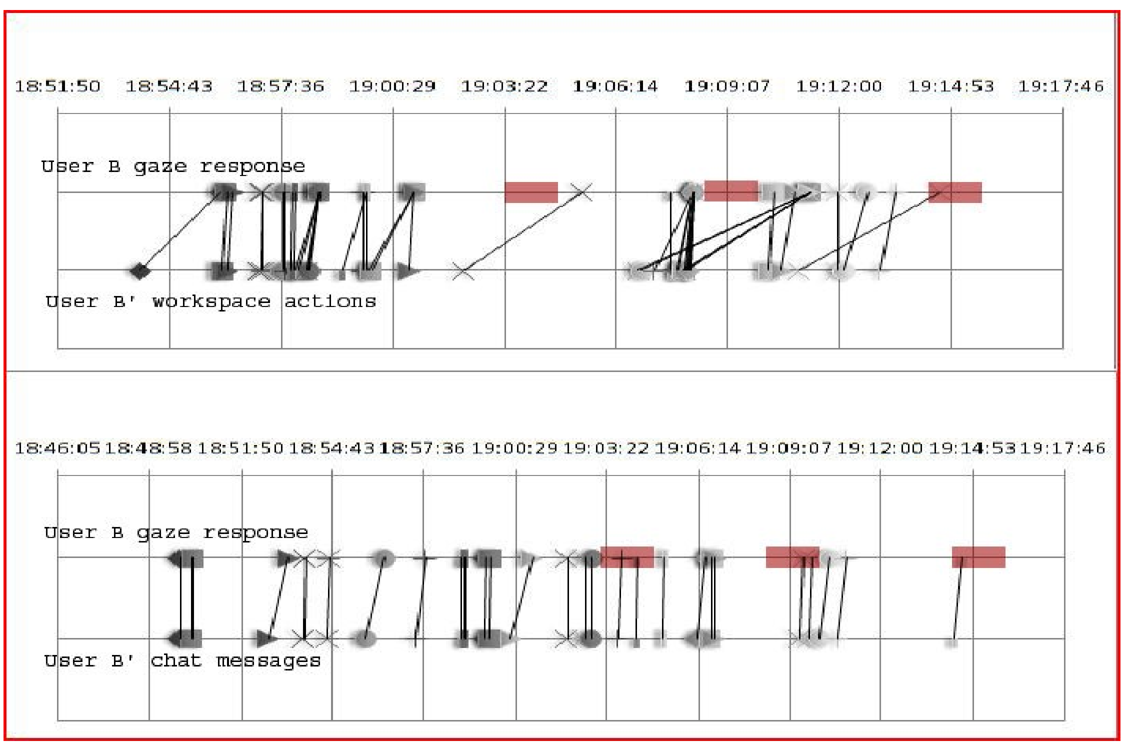

Figure 8. Gaze activity of User B regarding User's B' workspace and chat events

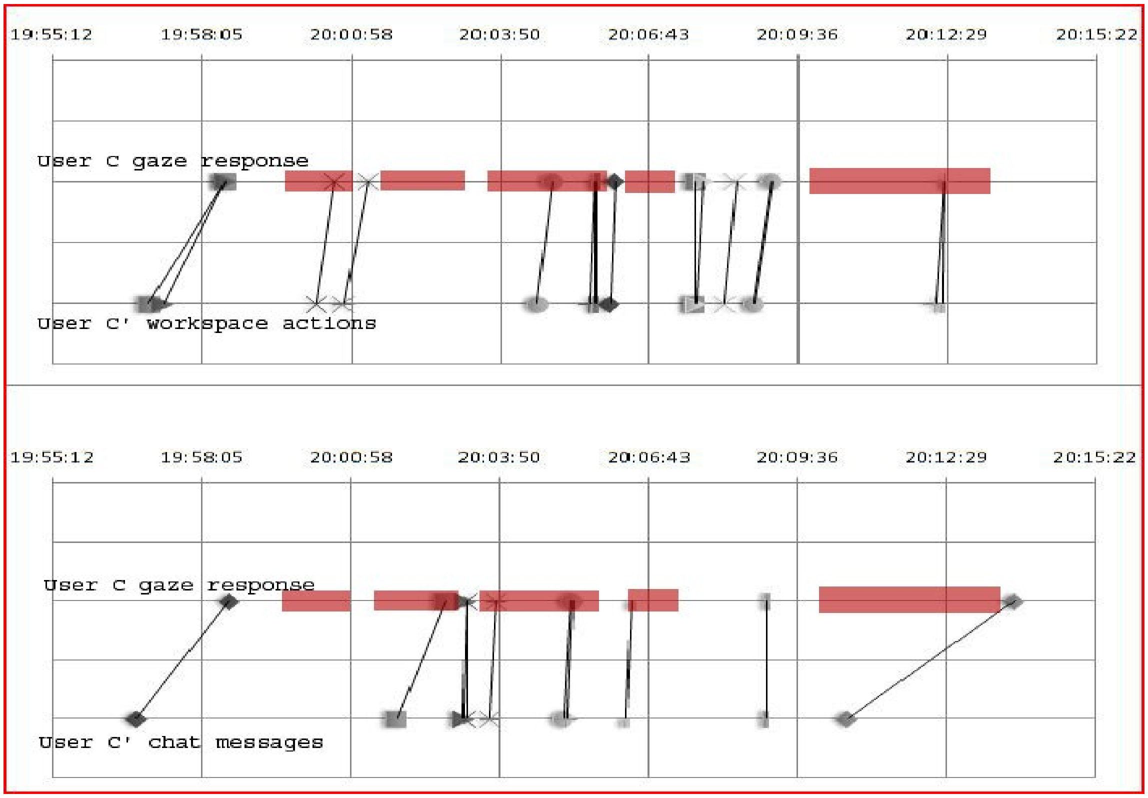

Figure 9. Gaze activity of User C regarding User's C' workspace and chat events