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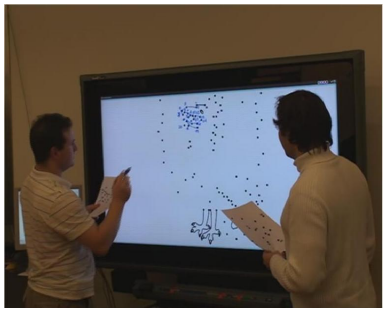
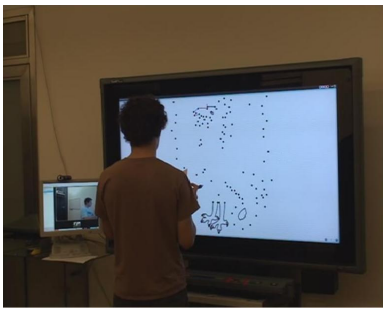


Measures of collaboration in CSCW:

Usability and collective measures in remote and co-located problem-solving

Master of Science Thesis in Intelligent System Design

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Cover:
The set-up from the experiment with two remote and one co-located collaborative problem-solving tasks. From the left: the Co-located, Skype-video and CollaBoard condition with participants from a study made in Zürich ETH.

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Abstract

Since computers first came to be used in the society the role of the user has changed as has the research connected to it. Computer Supported Collaborative Work (CSCW) has focused on several users and to evaluate existing collaborative systems. However, no full method is yet proposed. Authors state that there is a lack in usability and social studies. The aim of this thesis has first been to find new measures for collaboration and second to test the validity of these measures on a set of experimental data. A literature review showed that good candidates for new measures were usability an collective measures. A careful observation of the experimental data set helped to find seven candidate measures: *Speaking, Monitoring, Looking at task description, Sketching, Erasing, Laughing* and *Task process* that were applied on an existing body of experimental data. The collection of experimental data stemmed from video taped observations on a within-group design experiment involving eighteen participants. Nine pairs of subjects solved dot-to-dot puzzle problems under three conditions (first independent variable), two of these conditions were remote (SkypeVideo and CollaBoard); one condition was co-located (Co-located). There were three tasks with varying difficulty (second independent variable). *Monitoring* and *Speaking* were examined in statistical tests and the five other measures in descriptive analysis. Statistical significant difference in means were found for tasks in *Monitoring* and Speaking. In *Monitoring* the difference was due to the difference in task time. No significance was seen for conditions which could be due to a high variation as seen in the box-plots or that the conditions were too similar when solving the specific dot-to-dot puzzle problem. The descriptive data showed similar results. The *Task process* measure showed that in the Co-located condition most focus was put on task-solving, in Skype Video the most focus was put on the whiteboard. In the CollaBoard condition *Looking at task description* had the most focus and the most conversation and *Laughing* was seen. Most *Laughing* was also seen in the simple and hard task. Also the most focus on the whiteboard was seen with the simple task. Most task-solving was done in the average task which implies that in an average task more focus can be put on solving the task than on other things. The measures found in this study should be investigated further as well as measures of CSCW usability and collectivity in general. A more usable CSCW system may save time, money, and our environment.

Keywords: Computer Supported Collaborative Work (CSCW), collaboration, usability, evaluation and collective behaviour.

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1 Introduction

In this first chapter the background to the problem of usability and collaboration in Computer Supported Collaborative Work (CSCW) will be introduced (section 1.1). After this the aim of the study together with the driving questions will be presented (section 1.2). The meaning of some central concepts will be explained (section 1.3) and finally the outline of the thesis will be described (section 1.4).

1.1 Collaboration and evaluation in CSCW

Since computers first came big changes in technology and society has altered the way computers are used and also the research connected to them. When computers first were produced in the 1950s the users were considered to be alone, task-oriented and short termed (Grudin, 1990 and Neale et al., 2004). Today the users are several at a time, both co-located and remote and long term (Ibid.). The research method on evaluating Human-Computer Interaction (HCI) has changed from informal to formal while the cost of evaluation has grown evaluation steadily. In the beginning the focus was on electrical engineering then computer science moving iteratively to human factors, cognitive psychology and now social psychology and organisations (Grudin, 1990). Computer Supported Collaborative Work (CSCW) is one of the research areas that has sprung out from HCI-research. One central concern in CSCW has been to evaluate existing collaborative systems (Burkhardt, 2009).

To be able to evaluate a collaborative system the systems usability needs to be considered. Usability is an approach that focuses on the property of being usable and is often tested in a controlled environment (Sharp et al., 2009). Since a design of a system can make participants behave in different ways, (Nacenta et al., 2007) how people behave and think about a new technology or system is important in improving usability (Orlikowsky, 1992).

Understanding human expectations to tailor technology serving the human mind and behaviour flawlessly. A measure of success for CSCW systems mediating remote collaboration is how they reach making remote participants believe they were in the same place (Sharp et al., 2009). Some processes that are important in understanding the mind are: attention, perception and recognition, memory, learning, reading/speaking and listening and problem-solving (Ibid.). Most interesting are attention and problem-solving. Attention is the process of selecting what to concentrate on (Sharp et al., 2009). In any given instant the human senses are bombarded with information from the environment (Smith et al., 2003). Meanwhile the person is generally engaged in trying to solve some task. The task can be a simple one like drinking a coffee or walking but it can also be a complex task like a math test or doing surgery (Ibid.). When solving a problem people often use their beliefs or expectations in choosing what to do next (Reisberg, 2001). In some problems choosing what to do next is the same thing as deciding the goal. After deciding that there is still a process of how to reach the goal which is the domain of problem-solving (Ibid.). In reaching a goal the problem is divided into sub-goals. That are divided into sub-goals until a level where it is possible to solve the sub-goals is reached (Smith et al., 2003). Reaching the sub-goals can be done in several ways and are called strategies. A strategy includes reducing differences between the current state and the goal state where some problems can be solved with visual representation and others by concept representation (Ibid.). The way a problem is solved is different regarding expectations and beliefs, the strategy for reaching the goal, type of problem and type of person (novice or expert) (Reisberg, 2001 & Smith et al., 2003).

When designing to support collaboration it is important how people talk and move is important. In verbal talk the system needs to support the natural flow of talking, help people coordinate each

other and the shared work and awareness to be able to find out what is happening, what others are doing and to help others know what you are doing (Sharp et al., 2009). The physical body plays an important role in co-located collaboration because the consequence of our actions is important to get feedback about our next move (Tang et al., 2007). Only seeing the other person does not add the support in collaboration (Gaver et al., 1993).

Collaboration is affected by social processes and the work environment. Collaboration in both good and bad ways since the presence of others can enhances or impairs another persons performance (Sharp et al., 2009). What kind of people and how the group works is important in understanding collaboration and the work environment (Axelsson et al., 2005). For instance; have they worked together before, is there a clear explicit leader and what are the individuals main goal of the group work? Are the individual goals the same as the group goal then there will be less conflict (Ibid.). For the work environment to be successful a person needs to be able to be part of and manage the environment as well as the work (Rubenowitz, 2004).

Many collaborate systems exists today but there are often problems of usability and lack of social studies connected to them and until now no full evaluation method has been proposed (Baker et al, 2001). Neale et al. (2004) stated that evaluation in CSCW often has been vague defined, hard to implement and time consuming and states further that new strategies are needed to find out what is central in groupware success and failure. In doing this more measures need to be considered (Ibid.). Saeki (1995) mean that recent studies have focused on the characteristics of human behaviour instead of the artefacts produced by the work. Further, Tang et al. meant (2005) that there is a lack in long-term and daily studies and much studies has been made on either remote or co-located collaboration. Grudin showed (1988) that there is a lack in CSCW because it does not focus on peoples differences and that the support in collaboration has to be on an entire group. *"If we are going to support groups that include any diversity at all, we will have to learn much more about how different kinds of people work (p.91) ... We need to have a better understanding of how groups and organizations function and evolve than is reflected in most of the systems that have been developed" (p. 90).*

1.2 Aim of study and driving question

The aim of this thesis is to describe and understand previous research in CSCW research in order to find what measures has not been studied well before. These measures will be tested as they are applied on an experimental data set with the aim of seeing if and what contribution they may give to the research area. With the background of this background and aim, a driving question was formed: How can the measures be defined in order to contribute to the evaluation of CSCW systems?This driving question is examined in more detail through a set of seven research questions, presented in Table 17 in the Method chapter (Chapter 3).

1.3 Central concepts: Collaboration and Usability

The definitions existing for collaboration and usability will be investigated in the section and a definition for this thesis will be found and discussed. Firstly, collaboration has been defined by Sharp et al. (2009) as when people work together sharing a mutual goal while sharing information. Collaboration is defined in Wikipedia as a recursive process were two or more organisations or people work together on a shared goal by sharing knowledge, information and building consensus (Wikipedia 1). It is stated further that collaboration requires leadership but that it can be social in a decentralized or an egalitarian group. Some classical examples of collaboration are: trade, community organisations, game theory, military-industrial complex, project management and academia (Ibid.). Other definitions of collaborations are: to cooperative with someone for a shared goal (SAOL, 1997), the interaction among two or more individuals that encompasses a variety of

actions such as: communication, information sharing, coordination, cooperation, problem solving and negotiation (TechTarget, 2010). And in another definition collaboration is said to work together especially with a joint intellectual effort (The free dictionary, 2010). All these definitions have in common that they include two or more people or groups were some action is performed sharing a mutual goal. Some talk about leadership and that the action can be intellectual which will not be discussed further in this thesis. In this thesis collaboration is defined as two or more people that work together sharing a mutual goal.

Secondly, usability is defined in Sharp et al. (2009) as an approach that focuses on the property of being usable and is often tested in a controlled environment to see if the system or product is usable for the participants and the kind of task it was designed for. Usability is defined in Wikipedia as the property for something human-made to ease to use and to learn (Wikipedia 2). It is stated further that usability includes measuring usability, studying an objects efficiency or beauty. Further, usability can be measured with five components: learn ability, efficiency, memo ability, errors and satisfaction (Ibid.). In Sharp et al. (2009), the components are seen as usability goals: efficiency, effectiveness, safety, utility, learn ability and memo ability. Usability is also defined as the state of something being usable and second as the degree to which an object or product is easy to use without training (Wiktionary). Researchers at the University of Texas in Austin (2010) stated that usability is the simplicity to use, efficiency, learneability and error tolerability a product has. Another definition is that usability is the art and science to design products or systems that are easy to learn, efficient, effective, engaging and error tolerant (University of Minnesota Duluth, 2010). In this thesis usability is defined, in line with Sharp et al. (2009), as an approach that focuses on the property of being usable regarding ease of use, efficiency and satisfaction. These words are chosen because they are easy to understand and seem to be in line with the above definitions.

1.4 Thesis outline

In the following chapter the framework with the literature review will be presented (Chapter 2). After this the method for the literature study and the empirical study including the data collection, the data analysis and the evaluation method will be discussed (Chapter 3). Thereafter the empirical study containing the user study will be presented (Chapter 4). The results of this user study will be discussed (Chapter 5) and finally conclusions with implications for both practitioners and researchers will be presented (Chapter 6).

2 Literature review

A literature study was done in order to investigate what previous studies has studied and what not been well studied. First the method of the literature study is presented in which the chosen parameters are divided into two groups: frame of paper and study in paper. The papers were found using google scholar searching for “remote collaboration”, “distributed collaboration”, “co-located collaboration”, “mixed presence groupware” or “user study and collaboration” and with help from the supervisor and co-workers. If papers on other fields are found like for instance on Computer Supporter Collaborative Learning they were of interest if they contributed to the aim of the study. Six parameters were studied: *Method in paper, Kind of collaboration, Measure on collaboration, Method in study, Number of participants* and *Result*, Table 1. The first three parameters describe the Frame of the paper. *Method in paper* is for stating if the paper is theoretical or practical. The second parameter, *Kind of collaboration*, describes what kind of collaboration that is studied: Remote, co-located, mixed presence, both remote and co-located or neither. The third parameter is *Measures of collaboration*. The latter three parameters describe the user study. *Method in study* states what method is used in the user study. *Number of participants*, how many participants that was used and last what *Result* did the study have. Name of author/-s, year of publication and system analysed were noted.

The two parts Frame of paper and Study in paper of the literature study are described further below. First, the first two parameters of Frame of paper: *Method of paper* and *Kind of collaboration* were noted to see what had been studied the most and the least. *Measures of collaboration* were noted and divided into categories in order to see trends. *Measures of collaboration* were found from the paper introduction, abstract and content where, in the first step, no simplification or categorisation were done. Instead when a measure is found it was noted as named by author/-s. If two measures are similar to one another like for instance conversation and talking they were put together but if they seem to differ in some way like for instance: leader styles and social roles (where leader style is specific and the social roles can be any other people in the group) they were put separately. The measures were put separately if there is any doubt of different meanings. Second, in Study in paper the type of *Method in study* and *Number of participants* were noted to see what have been studied the most and the least. *Method in study* was found in abstract or method/content and *Number of participants* were found in method/content or conclusion. *Result* of the papers was found from the abstract, result and in the conclusion part of the papers. Only results important for the aim of the study were noted, that is if they said something about what support collaboration. Results concerning the system studied were not being mentioned.

In the following chapter, the collaborative aspects of previous research will be categorized (section 2.1). After that the results of this categorization will be presented in terms of frame of paper (section 2.2) and frame of study (section 2.3). Finally, some conclusions from this literature review will be discussed (section 2.4).

Table 1: Parameters in literature study

Parameters	Definition	Why interesting	How measured	Location in papers
Method in paper	Is the paper theoretical or not?	Statistical purposes	As noted by author	Introduction, abstract or content
Kind of collaboration	What kind of collaboration is studied in the paper? Remote/distributed, co-located, mixed presence groupware, both remote and co-located or neither	If result is found on what does improve collaboration it is important to know what kind of collaboration was studied in the paper	Words as noted by author	Introduction, abstract or content
Measures of collaboration	What measures was used and what were the author focusing on when they talked about collaboration?	Since collaboration is a hard word that is defined in different ways it is crucial to see what words are used to describe and measure it	Words as noted by author except for words that are similar which are considered to be the same words. For example conversation and talking.	Introduction, abstract and content
Method in study	What method is used in the paper?	If one type of method is used more often this will have an implication on why the evaluation methods have failed	Words as noted by author	Abstract or method/content
Number of participants	How many were the participants in the user studies?	Interesting to see what has been well studied and what has not	Numbers as noted by author	Method/content or conclusion
Result	What results about collaboration did papers have?	If something is already investigated and stated as true it is not interesting to investigate further	Only results important for the aim of the study were used	Abstract, result and conclusion

The Table (Table 1) describes what is studied in the literature study. The parameters are for Frame of paper: *Method in paper, Kind of collaboration* and *Measures of collaboration* and for Study in paper: *Method in study, Number of participants* and *Result*. There are description on how the parameters are defined, why they are interesting, how they are measured and where they were found in the papers.

2.1 Collaborative aspects in previous research

A literature review was done in order to investigate how collaborative aspects in CSCW has been studied in previous research. The studies are categorized in terms of Frame of paper and Study in paper. Frame of paper includes the parameters connected to the frame of the paper: (i) *Method in paper*, (ii) *Kind of collaboration* and (iii) *Measure of collaboration*. Study in paper includes parameters connected to the study in the paper: (i) *Method in study*, (ii) *Number of participants* and (iii) *Result*. The parameter *Result* includes conclusions of the paper. A full data table is seen in Appendix II.

The papers were found searching on google.scholar for “remote collaboration”, “distributed

collaboration", "co-located collaboration", "mixed presence groupware", "user study and collaboration"and "CSCW and user study". Some papers were found with help from the supervisor and colleges.

2.2 Frame of paper

41 papers (see Appendix I) on collaboration were read in which more than half were using a user study (N = 24), Table 2. In *Kind of collaboration* remote collaboration was found the studied (N = 24) where few had focused on remote and co-located, mixed presence or just co-located collaboration, Table 3. *In Measures of collaboration* 184 measures were found. The most studied measure where awareness, performance, gestures, conversation and natural behaviour, Table 4.

Table 2: Methods found in the 41 papers reviewed

Method in paper	Number of papers using method
User study	24
Theoretical	11
Descriptive	2
No formal study	1

The table (Table 2) shows method in paper and how many papers used that method. More than half of the papers performed a user study.

Table 3: Kind of collaboration found in the 41 papers reviewed

Kind of collaboration	Number of papers investigating kind of collaboration
Remote	24
Remote and co-located	5
Mixed presence	5
Co-located	4
Unspecified	3

The table (Table 3) shows what Kind of collaboration that was found in the papers and the number of papers that investigated that kind of collaboration. Most studies were focused on remote collaboration.

Table 4: Most studied measures found in the 41 papers reviewed

Most studied measures	Number of papers investigating measure
Awareness	17
Performance	14
Gestures	13
Conversation	13
Natural behaviour	11

The Table (Table 4) shows the most studied measures and the number of papers investigating that measure.

Measures of collaboration were divided into three categories: Human measures, Task measures and Usability measures, see Table 5. The Human category includes measures that are connected to the human emotion or activity for instance number of participants, roles, awareness etcetera. The Task category includes measures that are connected to the task or environment of the task or technology like for instance quality, interface, environment, shared artefacts etcetera and the Usability category includes measures connected to usability like for instance ergonomics and interaction. The most studied category was Human measures, 51.63 percent, Table 5. Human measures were divided into two subcategories: Individual measures and Collective measures were the Individual measures were the most studied, 68.42% of the Human measures, Table 6. The Individual category is connected to how one person feels or acts while the Collective category includes more than one person or object at the same time. An example of a Collective measure is presence disparity and ecology. The full table is presented in Table 7.

The least studied categories were Usability and Collective measures, see Table 8. The least studied Individual measures were: Eye gaze, grounding, author styles, learning, motivation, ergonomics, immersion, culture and need. The least studied Collective measures were: Casual interaction and monitoring. The least studied Task measures were: environment/place, physical objects, design, interface, technology, transition between activities, tool, information and feed through. The least studied Usability measures were: support for casual interaction, learning and ergonomics.

Table 5: Three categories of measures in the 41 papers reviewed

Measures	Number of papers investigating measures	Percent of measures
Human	95	51.63%
Task	58	31.52%
Usability	31	16.85%

The Table(Table 5) shows the three categories found in *Measures of collaboration*: Human, Task and Usability measures. The columns state the number of papers investigated by the measures and the percent of measures.

Table 6: Human measures found in the 41 papers reviewed

Human measures	Number of papers investigating measures	Percent of human measures
Individual	65	68.42%
Collective	30	31.58%

In Table 6 the Human measures are divided into two sub measures: Individual and collective measures and collective measures have been studied the least. The columns state the number of papers investigated by the measures and the percent of human measures.

Table 7: Use of measures counted in the 41 papers reviewed

Human measure	Count of papers using measure	Task measure	Count of papers using measure	Usability measure	Count of papers using measure
Awareness	17	Performance	14	Natural behaviour	11
Gestures	13	Coordination/management	9	Interaction	9
Conversation	13	Task process	6	Satisfaction	7
Embodiment	9	Feedback	5	Usability	3
Role	6	Sketching	5	Ergonomics	1
Presence disparity	6	Shared artefacts	4		
Individual versus shared	5	Work coupling	3		
Social organisation	4	Environment/ place	2		
Privacy	3	Physical objects	2		
Ecology	3	Design	1		
Perception/cognition	3	Technology	1		
Eye gaze	2	Transition between activities	1		
Casual interaction	2	Tool	1		
Grounding	2	Information	1		
Monitoring	2	Feed through	1		
Learning	1				
Motivation	1				
Immersion	1				
Culture	1				
Need	1				
Author style	1				
Total count of human measures	**95**	**Total count of task measures**	**58**	**Total count of usability measures**	**31**

The Table (Table 7) shows the *Measures of collaboration* found in the papers divided into three categories: Human, Task and Usability measures. The number of papers using the measure is also seen. The total number of measures are 184 and the total number for each of the measures can be seen in the end of the Number of papers using measure column were Human is the most studied and Usability is the least.

Table 8: Use of Individual and Collective measures counted in the 41 papers reviewed

Individual measure	Count of papers using measure	Collective measure	Count of papers using measure
Awareness	17	Conversation	13
Gestures	13	Presence disparity	6
Embodiment	9	Social organisation	4
Role	6	Ecology	3
Individual versus shared	5	Casual interaction	2
Privacy	3	Monitoring	2
Perception/cognition	3		
Eye gaze	2		
Grounding	2		
Learning	1		
Motivation	1		
Immersion	1		
Culture	1		
Need	1		
Author style	1		
Total sum of individual measures	**65**	**Total sum of collective measures**	**30**

In Table 8, Human measures are divided into two categories: Individual and collective measures. The total number of measures can be seen in the end of Number of papers using measure column were Individual measures are most studied and Collective measures are the least.

2.3 Study in paper

More than half of the *Method in studies* has been done with observation (N = 16) and experiments (N = 12) while other studied methods were: interview (N = 9), questionnaires (N = 8), Lab based (N = 7), logging (N = 5) and Video (N = 5). Least user studies has been done in notes or documents, long-term and daily studies, see Table 9. 27 papers did a user study were the most studied *Number of participants* was less than 15 (N = 8) and 15-30 (N = 7). The least studied *Number of participants* were more than 105 (N = 2), 45 to 60 (N = 1) and 60 to 75 (N = 1), see Table 10.

Table 9: Method in study counted in the 41 papers reviewed

Method in study	Count of papers using method
Observation (structured and unstructured)	16
Experiment	12
Interview (structured and unstructured)	9
Questionnaires (One or several)	8
Lab based	7
With logs	5
Video	5
Notes or documents	3
Long-term	3
Daily	2

In Table 9, the methods in the study is seen in the first column and the second show number of papers using method. The most used method were observation and experiment and least were notes or documents, long-term and daily user studies.

Table 10: Number of participants observed in the 41 papers reviewed

Number of participants	Count of papers using number of participant
Less than 15	8
15 to 30	7
30 to 45	4
90 to 105	4
More than 105	2
45 to 60	1
60 to 75	1

The Table (Table 10) shows what *Number of participants* were studied in the papers and how many papers used that number of participants. Most studied were less than 15 and 15 to 30 and least studied were more than 105, 45 to 60 and 60 to 75.

From the *Results*, measures that supported collaboration were divided into human, task and usability measures and summarised in Table 11. From the human measures awareness (Tang et al., 1991 and Gutwin et al., 2004), gestures (Heiser et al., 2004; Kirk and Fraser, 2005; Tang et al., 200t and Kirk et al., 2006) and casual interaction (Tee et al., 2009) were seen to support collaboration. Awareness was seen to enhance the sense of fellowship for co-workers (Tang et al., 1991) and was needed for remote developers to know more in detail who they were working with (Gutwin et al., 2004). Gestures were seen to help focus attention and to communicate solutions (Heiser et al., 2004) and were seen to be part of the collaborate process (Tang et al., 2007). Remote gestures were seen to significantly improve the performance but to reduce the rapport of communication (Kirk, 2005) and gestures with unmediated representation of the hands were seen to improve performance without loss of accuracy (Kirk et al., 2006). No significant difference was found in presenting them on external monitors or as projections (Ibid.). Presence disparity was seen important for MPG (Tang et al., 2004) but was in another study proposed not to be a problem (Epps et al., 2007). In another

study presence disparity was seen to have no significance for mixed presence groupware (MPG) and instead the opposite was seen (Bezerianos et al., 2008). Casual interaction was seen to support collaboration in Tee et al. (2009).

Task measures that were seen to support collaboration were shared sketch (Heiser et al., 2004 and Ju et al., 2006), sharing partial results (Neuwirth et al., 1994), having an automatic erasing tool (Fussell et al., 2004) and cursor pointing (Fussell et al., 2003). Collaboration was seen to be more efficient, showed better result and was more enjoyable with a shared sketch (Heiser et al., 2004) and it was showed that sketches in co-located collaboration support real time discussion but does seldom contain much information (Ju et al., 2006). Sharing partial results and managing the task is important for collaborative interaction (Neuwirth et al., 1994). An automatic erasing tool was reported to support collaboration (Fussell et al., 2004). Other task related results were that in collaboration with a physical task using multiple cameras task views was preferred over face views (Gaver et al., 1993). In a study by Scott et al. (2003) it was showed that small changes in a product design can lead to a large change in the systems ability to support collaboration.

Supporting natural behaviour (usability measure) was seen to support not only the collaboration but also the transition between a shared and a personal workspace, use of physical artefacts and user interactions (Saeki, 2003).

Table 11: Results found in 9 of the 41 papers reviewed

Measures	Supports collaboration	Author
Human measures - Individual measure	Awareness	Tang et al., 1991 Gutwin et al., 2004
Collective measure	Gestures	Heiser et al., 2004 Kirk and Fraser, 2005 Kirk et al., 2006 Tang et al., 2007
Collective measure	Casual Interaction	Tee et al, 2009
Task measures	Shared sketch	Heiser et al., 2004 Ju et al., 2006

The Table (Table 11) shows the *Results* that supports collaboration found in the 41 papers reviewed. Only results that supported collaboration were noted together with authors and year of publication.

2.4 Usability and collective measures

A literature study was done in order to find the most and least studied parameters in previous CSCW research. The least studied parameters are used to form an evaluation method for the user study. In Table 12 the least studied parameters and measures from the literature study is summarised. Last, the measures chosen for the thesis is presented.

Table 12: The least studied parameters from the literature study, based on the 41 papers reviewed

Parameter	Least studied in previous research
Kind of collaboration	Co-located, mixed presence and remote and co-located collaboration
Measure of collaboration	Usability and collective measures
Method in study	Long-term or daily studies using notes/documents, videos and logs
Number of participants	45-90 participants and more than 105 participants

Table 12, shows the least studied parameters and measures found in the literature study.

Due to delimitations some parameters could not be studied and a suggestion of measures was done. The evaluation method was used to make a basic setup and to choose measures for the user study. In *Kind of collaboration* it was seen that the least studied collaboration was Co-located, mixed presence and co-located and remote collaboration which can be done in the scope of the thesis. The least studied *Method in study* long-term and daily studies is delimited and therefore the next least studied measure is of interest. Notes and documents does not fit with evaluating a collaborate system and therefore Videos were used. As for *Number of participants* it is not possible to study more than 20 people although this is not the least studied. A summary of what can be studied in the scope of the study can be seen in Table 13. In *Measures of collaboration* it was seen that the least studied are Usability and collective measures. The Table for all the measures were used as an inspiration for finding measures in the study.

Table 13: Measures that can be studied

Measures that can be studied
Co-located, mixed presence and remote and co-located collaboration
Collective and Usability measures
Notes and documents, videos and logs

Table 13 shows which CSCW measures that have not been well studied and may therefore act as guidance towards novel research in the scope of the thesis.

The measures chosen for this study were remote and co-located and collaboration, usability and collective measures using video observations.

3 Method

The method is divided into three parts; literature study (chapter 2), evaluation method and analysis of experimental data set, see Table 14. In this chapter the method for evaluating the result from the literature study and the set-up for analysing the experimental data set is described. First the experimental design is explained (section 3.1). Methods for analysing the data is presented (section 3.2) and are divided into quantitative data (section 3.2.1) and qualitative data (section 3.2.2).

Table 14: Method

Method	Description
Literature study, 41 papers studied	Previous research on collaboration, shared whiteboards and related areas were read in order to see what has and has not been well studied before
Evaluation method	With help from the literature study and the theoretical frame an evaluation method was developed
Analysis of experimental data set	A user study was done in order to test the evaluation method

The method is seen in Table 14 and is divided into three steps: A literature study, an evaluation method and an analysis of experimental data set which is each described on how it was performed and why.

In the literature study measures was found that had not been well studied in previous research of CSCW. The evaluation method was used for finding measures for the user study and the set-up for the study. The least studied parameters from the literature study were used together with the delimitations in order to find measures usable for the user study. Background and theoretical information was also used. The results of the evaluation method are seen in section 2.4. The delimitations in the user study were that the study will not be able to include more than 20 participants during a short term study. Long-term or daily studies are not possible to do in the scope of this thesis. In order to test the measures found the data from a previous study was used. The design of that study and what data was used from it is explained in the next chapter.

3.1 Experimental design

This section explains the methods chosen for the analysis of the experimental data set. First the set-up (section 3.1.1, Video Observation) for the user study is explained. This section is divided into CollaBoard, Experiment and Participants. Then the Conditions (section 3.1.2), Tasks (section 3.1.3) and Measures (section 3.1.4) is explained. The data from the experiment were collected from videos and were analysed trough observation. The data gathering is explained further (section 3.1.5) and reflections of the chosen methods is seen in section 3.1.6.

3.1.1 Video observation

The user study originates from a study made by Tommaso Piazza in a licentiate thesis for Interaction Design, Chalmers University of Technology. Piazza's goal of the study was to see how CollaBoard, a new prototype, was perceived by the participants both trough questionnaires and through objective measures like for instance number of strokes performed, erasing done and interrupts from the remote participant (Piazza, 2010). The video material from the Piazza study was used and analysed with observation.

CollaBoard

A prototype called CollaBoard was developed at the Swiss Federal Institute if Technology in Zurich

(ETH) in order to make the HCI more seamless than before. The CollaBoard is a shared electronic whiteboard that allows a remote partner to work as they were side by side in front of it (t2i Lab, 2010). The difference from other existing shared whiteboards is that each participant is filmed with a camera from behind and that video in put in as an overlay on the remote participants' whiteboard. This makes pointing gestures visible directly in the whiteboard resulting in an intuitive collaborate teamwork (Ibid. and ETH, 2010). In a study on VideoArms, which is a system that captures arms and presents them as an overlay on the shared workspace, it was seen that the awareness support was improved (Andersson & Ehrensvärd, 2009). In another study using overlays participants though it was simpler to explain using overlays (Ibid.). Since the CollaBoard system supports gestures, awareness and a shared sketch it should be a more usable system than for instance VideoArms. This is possible since the characteristics described in turn supports collaboration, see literature study and Table 10. CollaBoard has new technology and many features that should support collaboration which makes it interesting to test in a user study.

Experiment
Two participants formed a group that tested three different tasks with three different conditions. Each subject in the pair (Participant 1 and Participant 2) was given a manual of the task. Participant 1 and 2 was given different manuals in order to stimulate collaboration (See manual in Table Z).The pairs were formed so that there was minimum chance that they had worked together before. The experiment was based on a problem solving task that should be solved as fast as possible with as few mistakes as possible. For each task a pair was given a maximum of 15 minutes to complete the task. When a task was completed the pair could move on to the next condition and task. Conditions and tasks were varied so that every group tested all conditions and tasks once. The order of the conditions and tasks were randomly varied so that the order of the conditions of tasks could not bias the experiment.

Participants
18 participants, 2 women, from the ETH University in Zürich were included in the user study (Piazza, 2009). Most of them was in their forties and between 24 and 61 years old were all of them work with computers for a daily basis. The most of them came from the same department (Ibid.).

3.1.2 Conditions
The conditions used in the study are Co-located, Skype Video and CollaBoard, see Table 15 (Piazza, 2009). Co-located means that the participants work side by side, in the same room, solving a task. In this setting two participants can not write at the same time which means that more monitoring was done, Figure 1. In the Skype video and CollaBoard condition two participants are situated in different rooms, sharing an electronic whiteboard. In the Skype Video condition a web cam is filming the participant while working on the whiteboard. An additional screen is put on the side of the shared screen so that each participant sees the remote partner in that screen, Figure 2 (Ibid.). In the CollaBoard condition the video conference prototype CollaBoard was used. The torso of the partner is seen as an overlay to the whiteboard (Figure 3). The conditions were ordered in order of evolution, Co-located came first, then Skype Video and latest the prototype CollaBoard.

Table 15: Conditions

Condition name	Definition
Co-located	Participants work side by side to solve a task on a shared whiteboard
Skype Video	Participants work remotely, seeing each other on an additional screen, to solve a task on a shared whiteboard
CollaBoard	Participants work remotely, seeing each other as an overlay in the work space, to solve a task on a shared whiteboard

The Table (Table 15) shows the condition name and definition.

In Figure 1, the Co-located conditions, participants work side by side to solve a task on a shared whiteboard. The participants are solving Task C – the dragon.

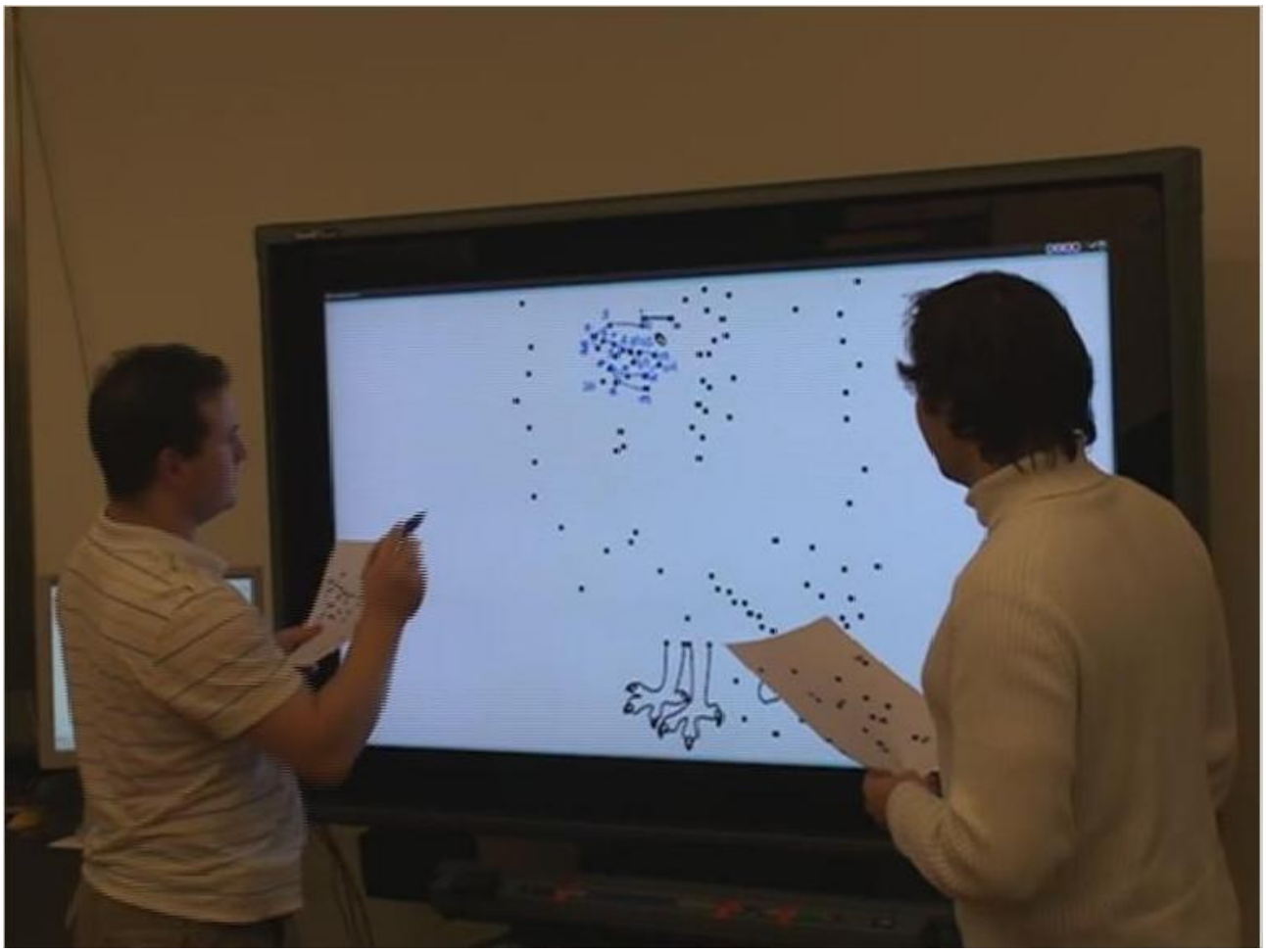

Figure 1: Co-located condition

In Figure 2, The Skype Video condition, participants work remotely, seeing each other on an additional screen, to solve a task on a shared whiteboard. The additional screen is seen on the left hand side of the whiteboard. The participants are solving Task C – the dragon.

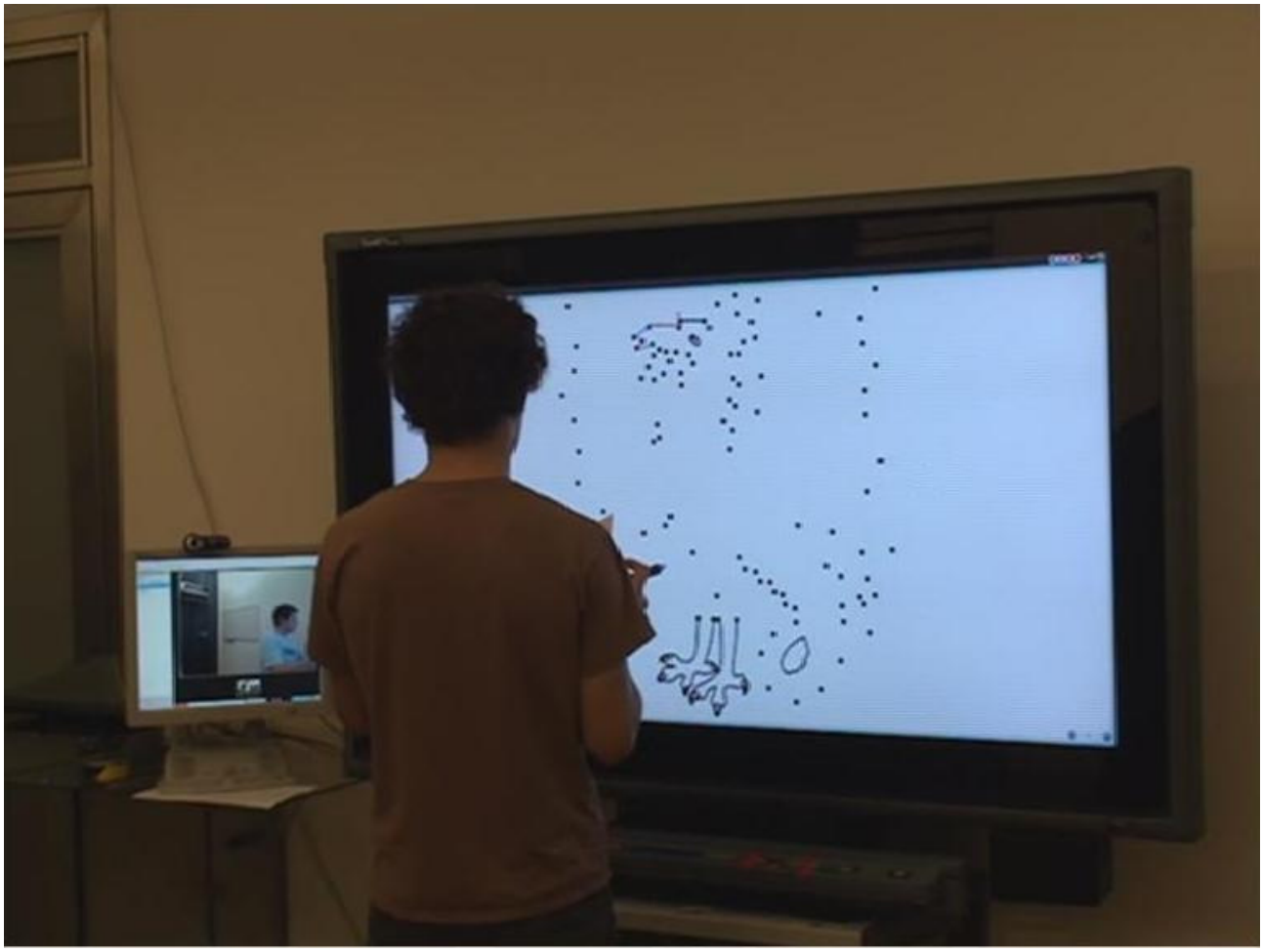

Figure 2: Skype Video condition

In Figure 3, The CollaBoard condition, participants work remotely, seeing each other as an overlay in the work space, to solve a task on a shared whiteboard. The participants are solving Task A -the knight's helmet.

Figure 3: CollaBoard condition

3.1.3 Tasks

The tasks tested in the study were dot-to-dot puzzles each representing a figure (Piazza, 2009). In order to stimulate collaboration the numbers connecting the dots were removed (except for the start and goal dot). Normal rules for completing puzzles were applied like for instance no pen lifting solutions and not going over a dot more than once. Each participant was given three tasks, dot-to-dot puzzles, with different degrees of difficulty. The tasks are ordered in difficulty and are called A, B and C and depicts a knight's helmet, a frog and a dragon, see Table 16. Task C was in advance tested in a smaller user study to be more difficult than the other tasks (Ibid.). An example of one of the Tasks A – the knight's helmet can be seen in Figure 4 and one of the participant manuals for that task is seen in Figure 5.

Table 16: Tasks

Task name	Description	Difficulty
Task A	A knights helmet	Easy
Task B	A frog	Average easy
Task C	A dragon	Difficult

Task name, description and believed difficulty is seen in Table 16.

An example of the dot-to-dot puzzles looked like is seen in Figure 4. This is Task A – the knight's helmet. The task is to draw the numbers in the correct order to finish to picture were each participant has a manual.

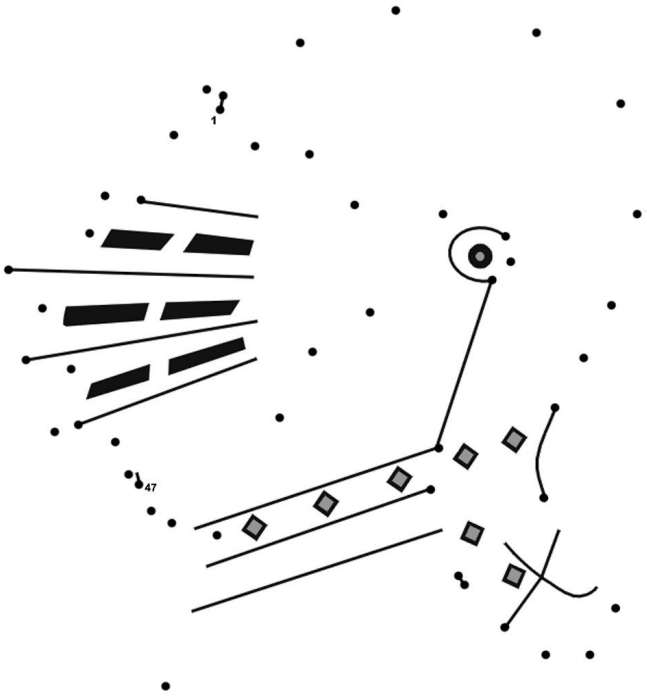

Figure 4: Dot-to-dot puzzle

The Figure (Figure 5) shows one of the manuals for Task A – the knight's helmet.

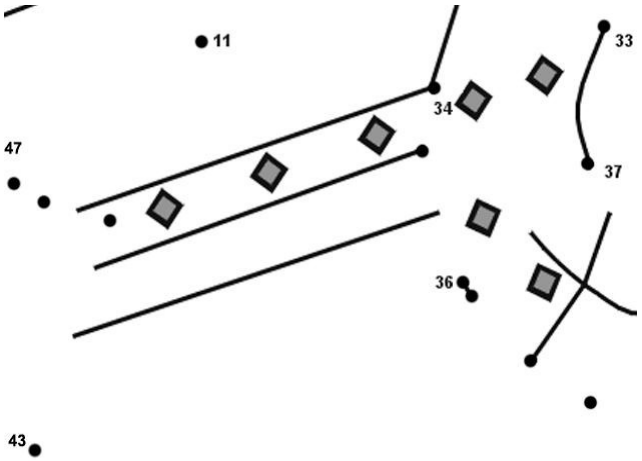

Figure 5: Manual for dot-to-dot puzzle

3.1.4 Measures

The measures for the experiment were chosen with the evaluation method with inspiration from the Hierarchical Task Analysis (HTA). Since the evaluation method showed that Usability and Collective measure has been the least studied in previous research these measures will be used. The HTA is used for its main idea to break down a task into subtasks and actions or operations (Crystal et al., 2004). After watching some of the videos the behaviour of the participants was divided into actions. One task session was divided into six quantitative measures: *Speaking, Monitoring, Looking at task description, Sketching, Erasing* and *Laughing*. One qualitative measures called *Task process* was chosen, see Table 17. The evaluation method was used for deciding what question the measures should answer and who or what will be the focus of the measure. All measures were chosen to be measured as Collective measures were *Laughing* also is seen as a Usability measure because it measures satisfaction. Some of them are also Task measures. The qualitative measure *Task process* is also measured as a Task measures. In Table 18 you can read about the definition of the action and how it was measured. One qualitative measure was chosen, *Task process*, which is seen as a summary of how the participants spend there time in each experiment.

Table 17: Research questions (RQ1-RQ7) and corresponding measures

Measure	Research question (RQ1-RQ7)	Type of measures
Speaking	RQ1: How does a participant interact with another participant in speaking or mumbling when solving a task?	Collective measure
Monitoring	RQ2: How does a participant look at/interact with the other participant (passive interaction) or watch the task progression when the other participant is doing something else?	Collective measure
Looking at task description	RQ3: How does a participant look at/interact with the given task to solve it?	Collective and Task measure
Sketching	RQ4: How does a participant interact with the shared whiteboard?	Collective and Task measure
Erasing	RQ5: How does a participant interact with the erasing tool when there is a problem with something that is written on the whiteboard?	Collective and Task measure
Laughing	RQ6: How does a participant interact with another participant showing enjoyability or confusion?	Collective measure and Usability measure
Task process	RQ7: How does the actions in a task solving process interact?	Task measure

Table 17 shows (left to right) seven research question, each question's corresponding measure as derived from HTA and intended to answer the research question, and type of measure.

Table 18: Operationalization of measures

Measure	Operationalization	Unit
Speaking	Starts when the participant says something to the other participant. Ends directly after.	Number of times
Monitoring	Starts when a participant is watching the other participant or the whiteboard without doing anything else. Since you cannot see the participants eyes. Monitoring is defined as when the other participant is standing still, watching the board not talking, not sketching or picking something up. Ends when the participant starts doing something.	Seconds
Looking at task description	Starts when the participant is reading his/her manual and ends when the participant starts doing something else.	Seconds
Sketching	Starts when the participant is sketching something (numbers or lines) on the whiteboard and ends when the participant starts doing something else.	Seconds
Erasing	Starts when the participant lifts the erasing tool and ends when the participant puts it back.	Seconds
Laughing	Starts when the participants laughs or giggles and ends directly after. Any kinds of laughter is measured.	Number of times

Table 18 shows (left to right) six measures, each measure's operationalization, and each measure's unit. The seventh measure, task measure, is left out because it is a qualitative measure.

3.1.5 Gathering the data

A software from Noldus was used when gathering data (see Observer XT at www.noldus.com). The input to the software was the videos and the definitions of the quantitative measures. In the software observation can be done while marking what action happen when in real time. The actions are predefined and when one of them occurs a short key for that action can be pressed marking the start of that action. When a new short key is pressed the previous action is marked as finished. Table 19 shows the measures and how they were marked in the software. The first four are mutually exclusive which means that they cannot occur at the same time while the last to *Speaking* and *Laughing* can and are measures as number of times not duration.

Table 19: Marking the measures

Measure	Marked as
Speaking	Non exclusive
Monitoring	Mutually exclusive
Looking at task description	Mutually exclusive
Sketching	Mutually exclusive
Erasing	Mutually exclusive
Laughing	Non exclusive

This Table (Table 19) shows the measures and how they are marked in the software. The first four are mutually exclusive which means that they cannot happen at the same time. When a new short key is pressed the action is marked as finished. *Speaking* and *Laughing* are measured as number of times and are non exclusive which means that when they are pressed the action starts and stops marking just the number of occurrences not the duration.

3.1.6 Reflections on the measures chosen

The pros of user studies and observation are that they are easy to perform, give insights about the social processes, have a high ecological validity, are holistic and give the observed point of view. Ecological validity means that they are context dependent and holistic means that they give explanations that includes a correlation of many measures. The cons of an observation are limits to what can be observed, reliability and that it can be hard to generalise the results. Since the researcher is subjective and the data comes directly from him or her it is hard to duplicate the study and measure the measures in the way that the researcher did. Watching a video and clicking on a button is subjective since it depends on one participant's reaction time. However since one participant makes the same mistakes and the same thing right at all times difference in two participants mistakes were not bias the study. Since many videos were watched, the response time for pressing the short keys could have changed over time. For example in the beginning the participant pressing the short keys may be extra reactive to changes and in the end the participant could have developed a skill for seeing when things are going to happen which means that the same occurrence would have different start and stop time if they happened in the beginning or in the end of the user study.

3.2 Analysing the data

Data from the experiment were collected in the Noldus software and were transferred to Excel sheets. Statistical consultants were hired from Chalmers in order to make a statistical setup of the analysis and to be able to give statistical advice. The analysis of the data was done in two steps: quantitative data (section 3.2.1) and qualitative data (section 3.2.2). The quantitative data were analysed with ANOVA and Poison regression and the qualitative data were analysed in a frequency- and a trend analysis.

3.2.1 Quantitative analysis

The difference of the mean scores of each of the measures was investigated in a two-way ANOVA or a Poison Regression. ANOVA was used for the measures producing duration values (*Monitoring, Looking at task description, Sketching* and *Erasing*) since Poison Regression was used for the measures that does not produce normal distributed values (the measures: *Speaking* and *Laughing*). Task and conditions are independent variables and *Speaking, Monitoring, Looking at task description, Sketching, Erasing* and *Laughing* are dependent. The variables and set-up for the analysis is seen in Table 20 and 21.

Table 20: The independent and experimental values for the study

Independent variables	Experimental values
Condition	Co-located, Skype-video and CollaBoard
Task	A, B and C

In the Table 20, the independent and experimental values for the experimental data analysis are seen.

Table 21: The dependent variables/measures for the experimental data analysis

Dependent variables/measures	Model assumed	Unit
Monitoring	Normal, 2-way ANOVA	Duration; seconds
Looking at task description	Normal, 2-way ANOVA	Duration; seconds
Sketching	Normal, 2-way ANOVA	Duration; seconds
Erasing	Normal, 2-way ANOVA	Duration; seconds
Speaking	Poision	Frequency; 1/seconds
Laughing	Poision	Frequency; 1/seconds

Table 21 shows (from left to right) the dependent variables also called measures, the model assumed and their units.

In order to perform these calculations SPSS was used. In order to see significance in the data a primary and secondary measure were chosen. According to a Bonferroni correction the p-values has to be lower than 0.025 instead of 0.05 If all measures were evenly chosen for a significance test each of the tests would have to have a p-value lower than 0.0083 in order to be significant. Two variables were chosen as a primary and secondary measure sharing the 5 percent. Since the 5 percent also can be chosen so that the sum of the percent is 5 the two measures were divided into 3 and 2 percent, Table 22. The primary measure was chosen to be *Speaking* and the second measure was chosen to be *Monitoring*. The hypothesis is that *Speaking* and *Monitoring* will have greater differences for Condition and Task than the other measures since they are more required for collaboration than the others. *Speaking* is thought to be more interesting than *Monitoring* since it was seen in the videos that there were a bigger difference in *Speaking* than for *Monitoring*. The other measures were analysed descriptively (*Sketching, Looking at paper, Erasing and Laughing*) which means that they were analysed in the same way as the primary and secondary measure but that the significance was not be considered. Since there were some zeroes in the data and since the data from two participants are dependent they were put together forming a pair wise data.

Table 22: Correction of p-values

Measures	Percent of significance that the p-value in the statistical models should be lower than
Speaking	0.03
Monitoring	0.02

The Table (Table 22) shows the description on how the percent for the significance value were chosen. Since two values were chosen to be tested for significance 5 percent was divided in two parts (3 percent for *Speaking* and 2 percent for *Monitoring*). The p-value in the statistical test should be lower than these percentages in order for the test data to be statistically significant.

Two way ANOVA

A two-way ANOVA can be conducted to see if there are significant differences between the conditions and tasks for the measures. Some assumptions are made: that the populations that the samples have been taken from are normally distributed or at least approximate to normal (Stats of Psychology). That the samples are independent and that the variances of the populations are equal and that the sample sizes are the same (Ibid.). A summary of the assumptions is seen in Table 23.

The two independent variables in the two-way ANOVA are called factors. The factors in this experiment are the condition and the task. Main effects are tested first which means that just one factor is tested at a time. Later the interaction effects can be tested to see if one factor influences the other factor. If no interaction effects are seen it is safe to check the main effects (Pallant, 2007). The setup for the two-way ANOVA was done according to the procedure manual in SPSS, page 259.

Table 23: Assumptions for ANOVA

Assumptions
The populations are normally distributed or at least approximate to normal
The samples are independent
The variances of the populations are equal
The sample sizes are the same

Table 23 shows the assumptions made for performing a two-way ANOVA.

Poison Regression

In the experiment some of the measures are frequencies and are therefore transformed in SPSS to Poison distribution. The setup for the Poison regression was done following the consultants from Chalmers. The procedure was written with inspiration from the procedure for two-way ANOVA in SPSS Survival Manual (Pallant, 2007, p. 259).

Procedure for Poison Regression

1. From the menu at the top of the screen, click on Analyse, then click on Generalized Linear Model, then on Generalized Linear Models.
2. Click on the Type of Model button.

Under Counts choose Poison Loglinear

3. Click on the Response button.

Click on the dependent variable, continuous variable, and move it into the box labelled Dependent

variable.

4. Click on the Predictors button.

From the factors listed on the right hand side, choose the independent variables (in this case Condition and Task). Click on them and move them to the box labelled Factors.

5. Click on the Model button.

Click on the factors and scroll down in the Build types to find Main effect and move them to the box labelled Model. If you are interested in Interaction effects. Mark the factors and choose Interaction in the Build types scrolling list and move them to the box labelled Model.

6. Click on the Statistics button

Click on Include exponential parameter estimates.

7. Click on OK

3.6.2 Qualitative analysis

The qualitative data are action-over-time-graphs that come from the Noldus software. These graphs were created when the user study was performed, when the short keys for every action are pressed it formed a graph were all actions are seen in order of appearances. Each action forms a block that shows the duration of the action and the start and stop time. These graphs were analysed qualitative by comparing the graphs to each other and quantitative by calculating and comparing number of action changes. With this graph a deeper investigation of the *Task process* was made.

The analysis was done in two steps, see Table 24. First a frequency analysis over the action changes was calculated to see if there are any changes of action-blocks in conditions or tasks. An action change consists of two action-blocks which are counted to see how many of every change there exists. This way the qualitative data can be analysed in a quantitative way. The differences between groups were also investigated. The second step is to analyse each graph overall in order to investigate trends, this is called the qualitative analysis. In the qualitative analysis the order of the action changes were analysed to see if there are differences in conditions, tasks or groups. Also the behaviour of the participants and the size of the action-blocks were observed.

Table 24: The qualitative analysis

Qualitative analysis	Difference in Condition, Task and Group
Frequency analysis	Number of action-block changes
Trend analysis	Trends in action-block changes, participant behaviour and size of action-blocks

The Table (Table 24) states how the qualitative analysis was performed. The *Task process* were analysed with a frequency analysis that looked at the number of action-block changes and a trend analysis that focuses on the trends of the changes, participant behaviour and the size of the action-blocks.

Frequency analysis

The action-over-time-graphs were analysed in a frequency analysis in order to see if there are changes in number of action changes in Condition, Tasks or Groups. Some assumptions are made to simplify the calculations, Table 25. First an action-block is counted only once because it is assumed that a participant goes from one action to another and later back again. This means that the order of the action-blocks in the action change is not noted. The second assumption is that if the actions are uneven the last action-block was not counted, however if an action-block is started but not finished in one task session it is counted since duration of the action is not considered. The action changes are given shorter names in order to simplify Table-writing and understanding, Table 26.

Table 25: Assumptions for frequency analysis

Assumptions	Calculation simplification
The number of changes going from action 1 to 2 is the same for going from 2 to 1	An action-block is counted once and for example Monitoring to Sketching is the same as Sketching to Monitoring
If there are an uneven number of actions the last one was not be counted	Since the action changes are counted in pairs the last action-block was not be counted if the actions are in an uneven number
Since the duration of a block is not considered an action-block that is not within the time-limit of a task is counted as a whole block	An action-block counts even though it is not a whole block

The assumptions for the frequency analysis and what calculation simplifications they give are seen in Table 25.

Table 26: Action changes

Action changes	Notation
Monitoring - Looking at task description or Looking at task description - Monitoring	Looking at task description and Monitoring
Monitoring - Sketching or Sketching – Monitoring	Monitoring and Sketching
Looking at task description - Sketching or Sketching - Looking at task description	Looking at task description and Sketching
Monitoring - Erasing or Erasing - Monitoring	Erasing and Monitoring
Sketching - Erasing or Erasing - Sketching	Erasing and Sketching
Looking at task description - Erasing or Erasing - Looking at task description	Erasing and Looking at task description

Table 26 shows the names and notations for the action changes.

Trend analysis

The action-over-time-graphs were analysed in a qualitative analysis in order to see if there are trends in the overall graph in conditions, tasks or groups. The trend analysis was done on the order of action changes, the participant behaviour and the sizes of action-blocks.

4 Results of the experimental data set

This chapter describes the results of the study. First, a short description of the user study is made (section 4.1). The user study is divided into Experiment (section 4.1.1) and Measures (4.1.2). Then, the empiri is divided into two parts: the quantitative data (section 4.2) and the qualitative data (section 4.3).

4.1 User study

The study was conducted at ETH in Zurich between the 10th and 16th of December, 2009 (Piazza, 2009). Eighteen participants was paired into 9 pairs. Each pair was formed to, as much as possible, make sure that they had not worked together much before. All participants came from the same department. The study included an instruction session, a training session with the technology followed by three task session where the two participants worked together solving three tasks in three conditions (Ibid.).

4.1.1 Experiment

Before the study started the participants got instructions about the tasks and conditions, through pre recorded videos. After that the participants got a five minutes training session and were given a training puzzle to solve without help from the experiment leaders (simpler than the original tasks). The participants did three tasks, all tasks in the same occasion, in a predefined order. The order was chosen so that the order of the task or the order of the condition would not bias the experiment result. The time and rate for finishing the tasks in the task sessions are seen in Table 27. Task C was seen to be the hardest task were only 33.33% finished the task.

Table 27: Mean time and rate of finished tasks in task sessions

Task	Mean time on tasks in minutes	Rate of how many participants finished the task
A	39.93	100%
B	64.12	100%
C	128.61	33.33%

The Table (Table 27) shows the time that all groups took in finishing the task, the time on task. Even though the task should take only 15 minutes maximum to finish, the video recordings sometimes lasted longer. Task C was a difficult task since only 33.33% finished it.

4.1.2 Measures

The measures was defined in the Noldus software and programmed with short keys. Since it was possible to select mutually exclusive or non exclusive measures *Monitoring*, *Looking at task description*, *Sketching* and *Erasing* were selected as mutually exclusive. *Speaking* and *Laughing* was selected as non exclusive. The videos were watched going from the first group to the last, in the order of CollaBoard, Co-located and Skype Video condition. The full order of the videos watched can be seen in Appendix III. The measures were observed in the videos while simultaneously pressing short keys to define the measure. The videos could be stopped in order to go back if something was missed. After this was done the data could be seen the automatically produced data sheet or in the produced graphs.

First all videos from Room 1 was watched and then the ones from Room 2 filming Participant 1 and Participant 2 respectively. The camera was slightly tilted in the settings, in Room 1 the camera was

placed almost straight behind the participants and in Room 2 it was placed filming the participant from the left.

4.2 Quantitative data

The quantitative data from the primary and secondary measures will first be presented, *Speaking* (section 4.2.1) and *Monitoring* (section 4.2.2), followed by the descriptive data from the rest of the measures (section 4.2.3), *Looking at task description, Sketching, Erasing* and *Laughing*.

4.2.1 Primary measure - *Speaking* (RQ1)

A linear regression was first done on *Speaking* and Condition and then on Task in order to see if there is significant correlation. Remember that in order for the primary measure to be significant the p-value needs to be smaller than 0.03. The linear regression showed no significance for Condition, $p = 0.54$, and statistical significance for Task, $p < 0.001$. The effect of Task ($b = 25.06$, $p = 0.001$) is significant and its coefficient is positive indicating that the higher difficulty in task the higher amount of *Speaking*. However, since the differences between time on task can contribute to the significance, a multiple regression was done. The multiple regression showed that there was significant correlation, between *Speaking* and Time on task ($b = 0.054$, $p = 0.000$) and the coefficient $B = 0.897$ is positive and that no significant correlation could be seen for *Speaking* and Task ($b = -1.354$, $p = 0.82$, $B = -0.03$) (the calculations for *Speaking* are seen in Appendix IV).

Parameter Estimators can be seen in Table 28 and in the box-plots, Figure 6 and 7. It is seen that the means of conditions are similar to one another but that the means for tasks differ. In the graph for means Task C differs from Task A and B, see Figure 8. The same is seen in the table and the box-plot.

Table 28: Parameter estimators for Speaking

Condition	Mean	Standard Deviation	Median	Number of data
Co-located	56.44	18.97	54.00	9
Skype Video	64.00	32.66	71.00	9
CollaBoard	67.11	44.45	50.00	9
Task	**Mean**	**Standard Deviation**	**Median**	**Number of data**
A	52.11	27.23	49.00	9
B	42.67	24.78	42.00	9
C	92.78	29.99	87.00	9

The Table (Table 28), shows the parameter estimators for *Speaking*. The means for conditions are similar to one another while the means for task differ.

Figure 6 shows the means, median and whiskers for *Speaking* and Condition. The values and medians for Condition 1, 2 and 3 is similar where Condition 3: CollaBoard has a bigger spread than the others.

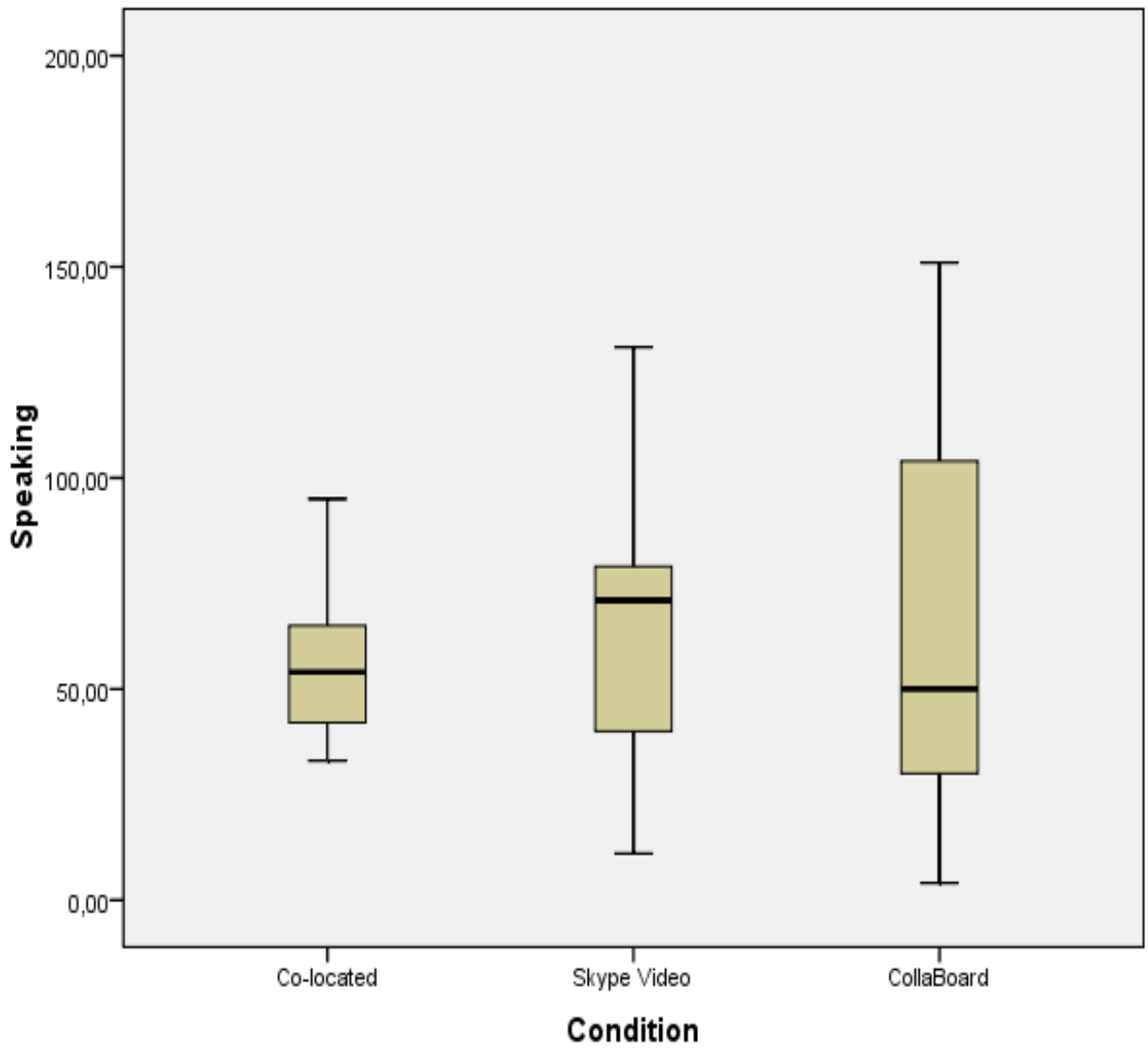

Figure 6: Box-plot for Speaking and Condition

In Figure 7, the means, median, whiskers and outliers for *Speaking* and Task is seen. The medians for Task A and B are similar, while Task B has outliers. Task C has a higher median and values than Task A and B. Task C also has a big spread.

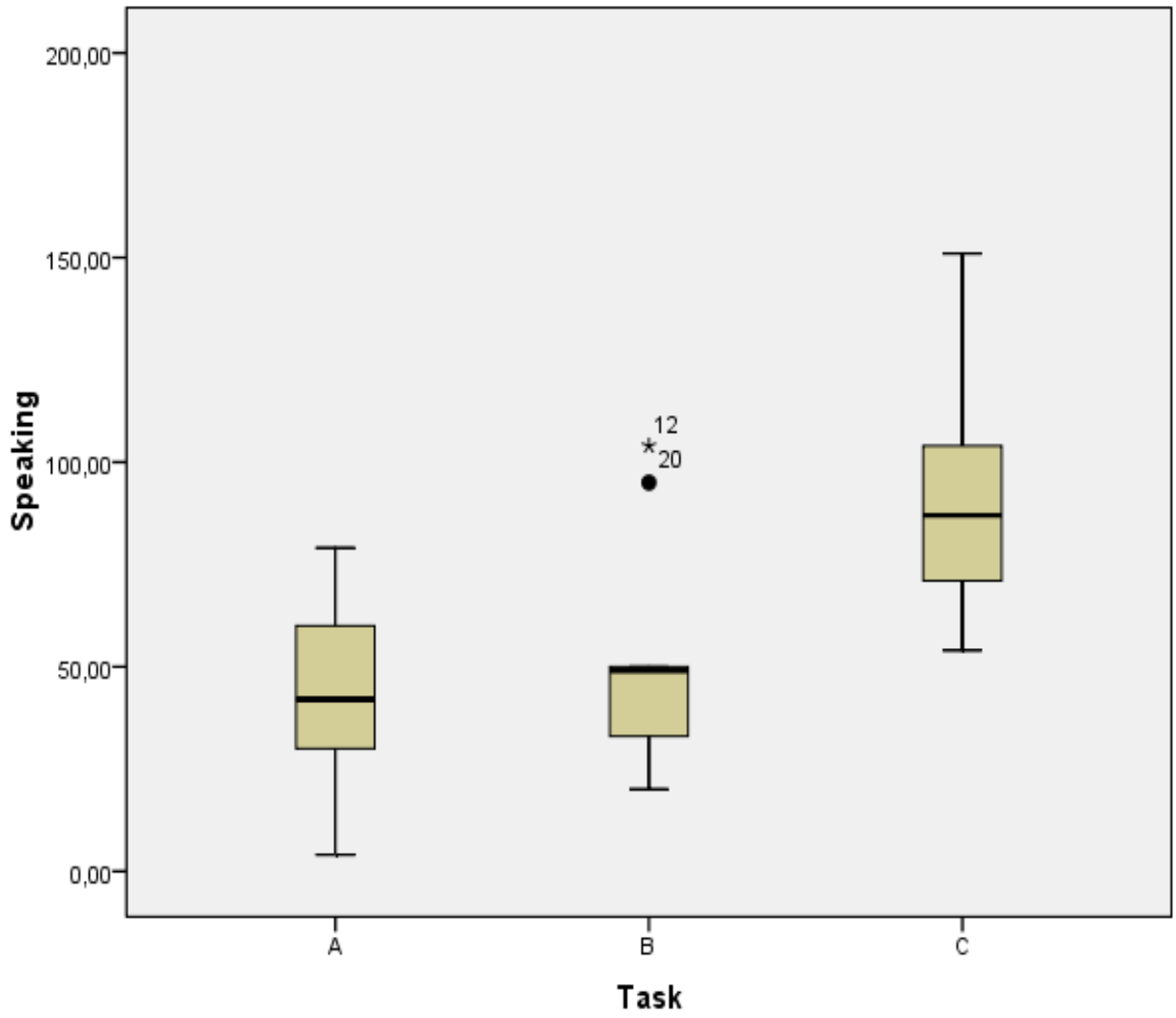

Figure 7: Box-plot for Speaking and Task

In Figure 8 the estimated marginal means of *Speaking* for Condition and Task is seen. Condition is seen on the x-axis and Task is colour-coded. Task C is seen to be different from Task A and B. There was a significance seen for Task which depended on Time on task. No significance was found for Condition or interaction effects.

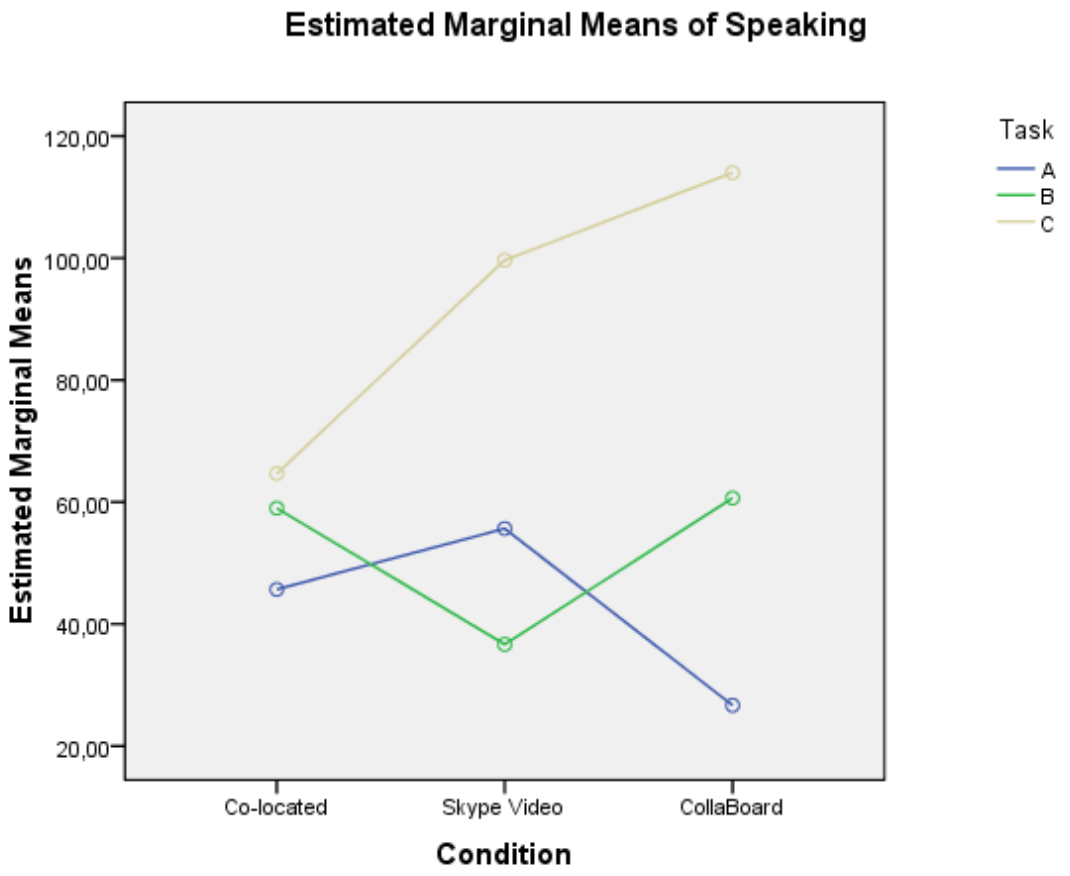

Figure 8: Graph for Speaking

4.2.2 Secondary measure – *Monitoring* (RQ2)

A two-way analysis of variance was conducted to explore the impact of Task and Condition on *Monitoring*. Subjects were given three tasks (Task 1: A, Task 2: B and Task 3: C) during three different conditions(Condition 1: Co-located, Condition 2: Skype Video and Condition 3: CollaBoard). The interaction effect between condition and task was not statistically significant, $F(4, 18) = 2.61$, $p = 0.07$. There was a statistically significant main effect for task, $F(2, 18) = 7.95$, $p = 0.003$, the effect size was big 0.47. Post-hoc comparisons using Tukey HSD test indicated that the mean score for Task C ($M = 1120$, $SD = 333.7$, $N = 9$) was significantly different from Task A ($M = 495.31$, $SD = 419.2$, $N = 9$) and Task B ($M = 636.2$, $SD = 395.81$, $N = 9$). The main effect for the condition, $F(2, 18) = 0.40$, $p = 0.68$, did not reach statistical significance. That is, the difference in mean can be explained by task with 46.9 percent (the calculations are seen in Appendix IV).

A linear regression was done in order to see if Time on task can explain the significance for Task seen in the ANOVA. The linear regression showed that *Monitoring* depends on both Time on task and Task. The effect for *Monitoring* and Time ($b = 0.837$, $p = 0.000$) had a positive coefficient $B = 1.09$ which means that the more time, the more *Monitoring* is done. The effect for Task (b =

-100.27, p = 0.01) had a negative coefficient B = -0.18 indicating that the higher the difficulty the lower degree of *Monitoring*.

A pair wise ANOVA was made in order to find out which Task differs significantly from which. A one-way between-groups analysis of variance was conducted to explore the impact of Task on *Monitoring*. Subjects were given three tasks (Task 1: A, Task 2:B and Task 3: C). There was a statistical significant difference at the $p < 0.05$ level for the three tasks: $F(2, 24) = 6.52$, $p = 0.005$. The effect size, calculated using eta-squared, was 0.35. Post-hoc comparisons using Tukey HSD test indicated that the mean score for Task A (M = 495.31, SD = 419.2, N = 9) was significantly different from Task C (M = 1120, SD = 333.7, N = 9). Task B (M = 636.2, SD = 395.81, N = 9) was not statistically significant from either Task A or Task B, see Figure 9.

In Figure 9 the means of *Monitoring* and Task is seen.

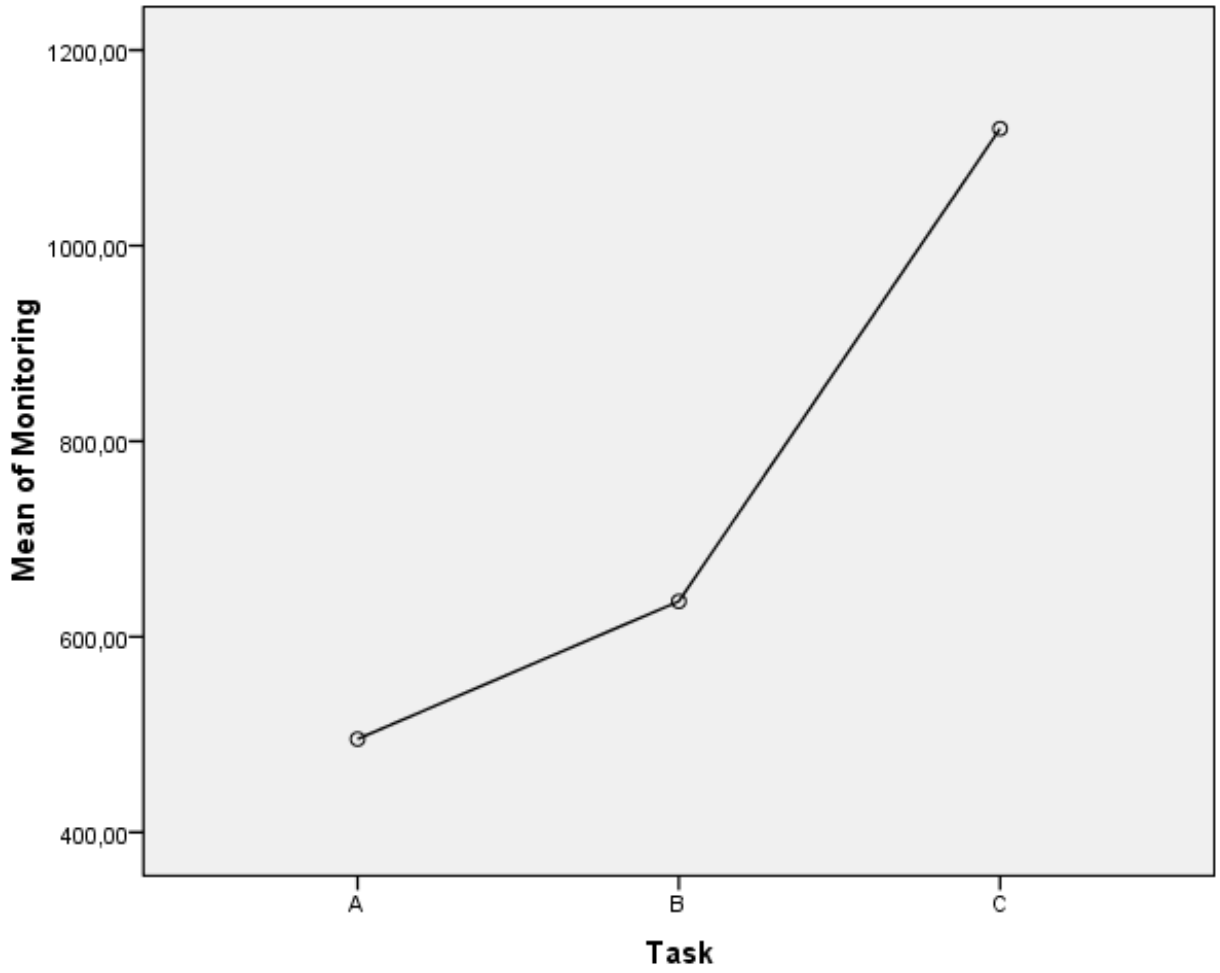

Figure 9: Graph for means of Monitoring and Task

Parameter estimators for *Monitoring* are seen in the Table 29. The means for conditions are similar in value where CollaBoard has a higher value than the others. The difference in Task can be seen in the table and the box-plots. The box-plots for *Monitoring* is seen in Figure 10 and 11 and the graph is seen in Figure 12.

Table 29: Parameter estimators for Monitoring

Condition	Mean	Standard Deviation	Median	Number of data
Co-located	669.82	338.92	558.57	9
Skype Video	767.73	506.77	579.14	9
CollaBoard	813.93	549.02	822.41	9
Task	Mean	Standard Deviation	Median	Number of data
A	495.31	419.20	347.65	9
B	636.20	395.81	459.34	9
C	1119.97	333.73	1199.32	9

In the Table (Table 29) the means of *Monitoring* for conditions are similar to one another but the mean for tasks differ. The mean of Task C is higher than of Task A and B which are similar in value.

Figure 10 shows the means, median and whiskers for *Speaking* and Condition. The means, medians and spread are similar for the three conditions.

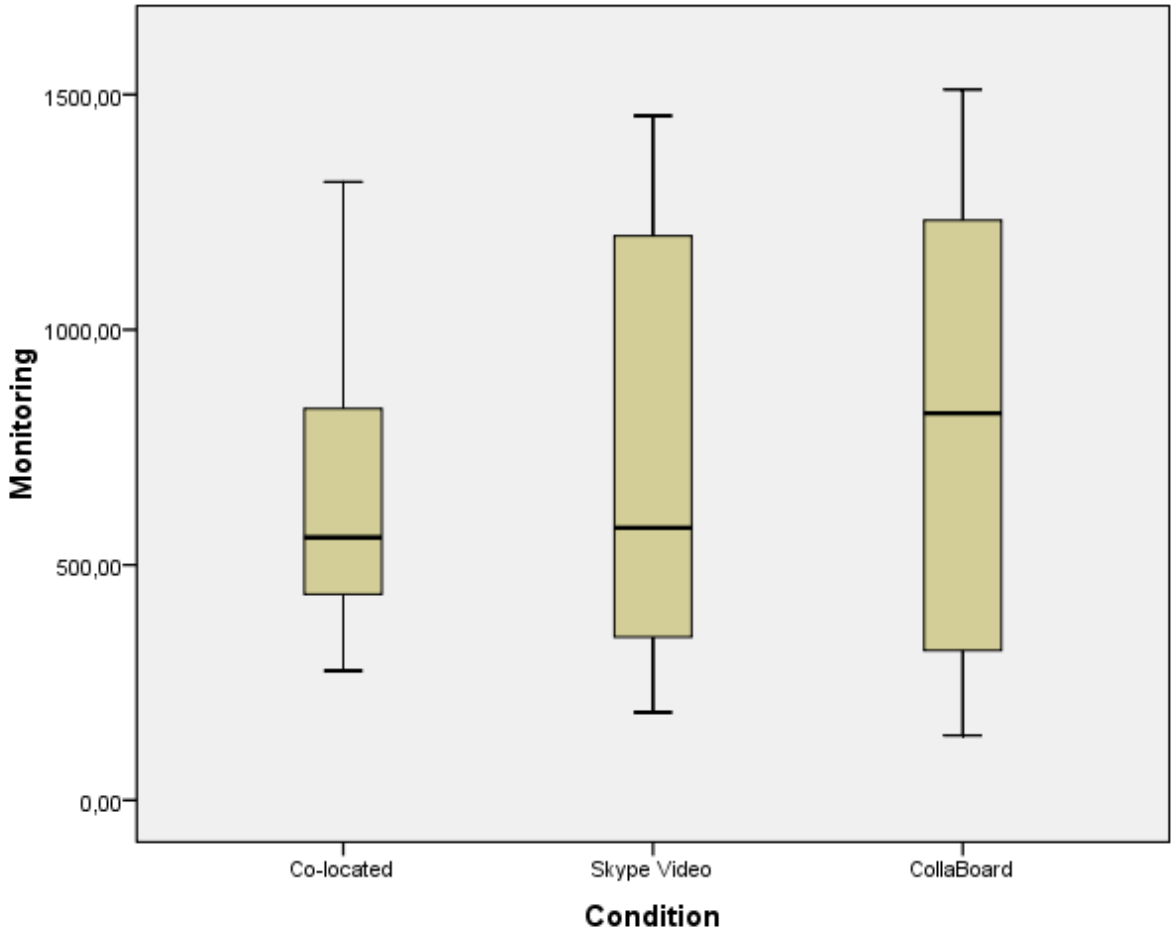

Figure 10: Box-plot for Monitoring and Condition

Figure 11 shows the means, median and whiskers for *Monitoring* and Task. Task A has one outlier and Task B and Task C has big spreads. Again, the means for Task C is bigger than Task A and B.

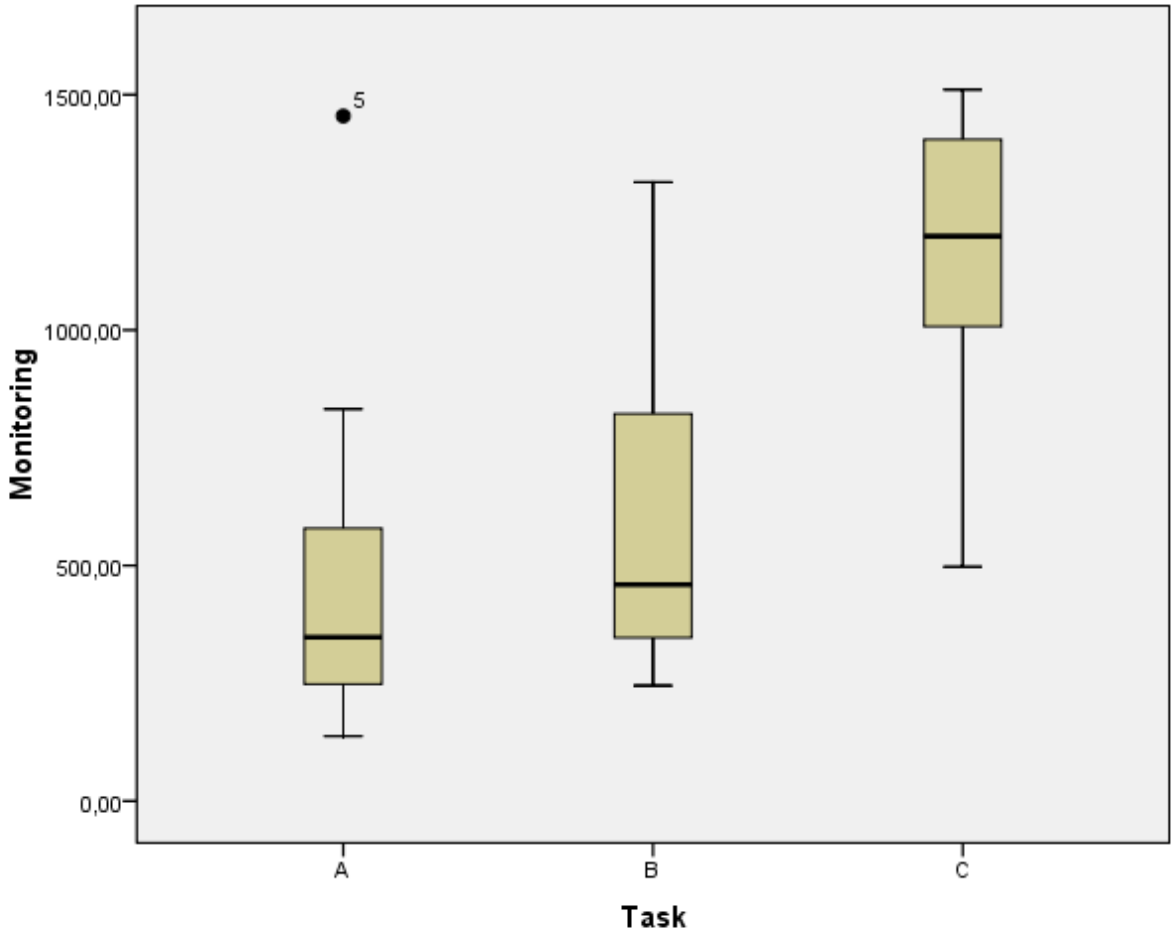

Figure 11: Box-plot for Monitoring and Task

The Figure (Figure 12) shows the graph for marginal means of *Monitoring* where Condition is on the x-axis and Task is colour-coded. There is a difference in Task. No significance was found for Condition or interaction effects.

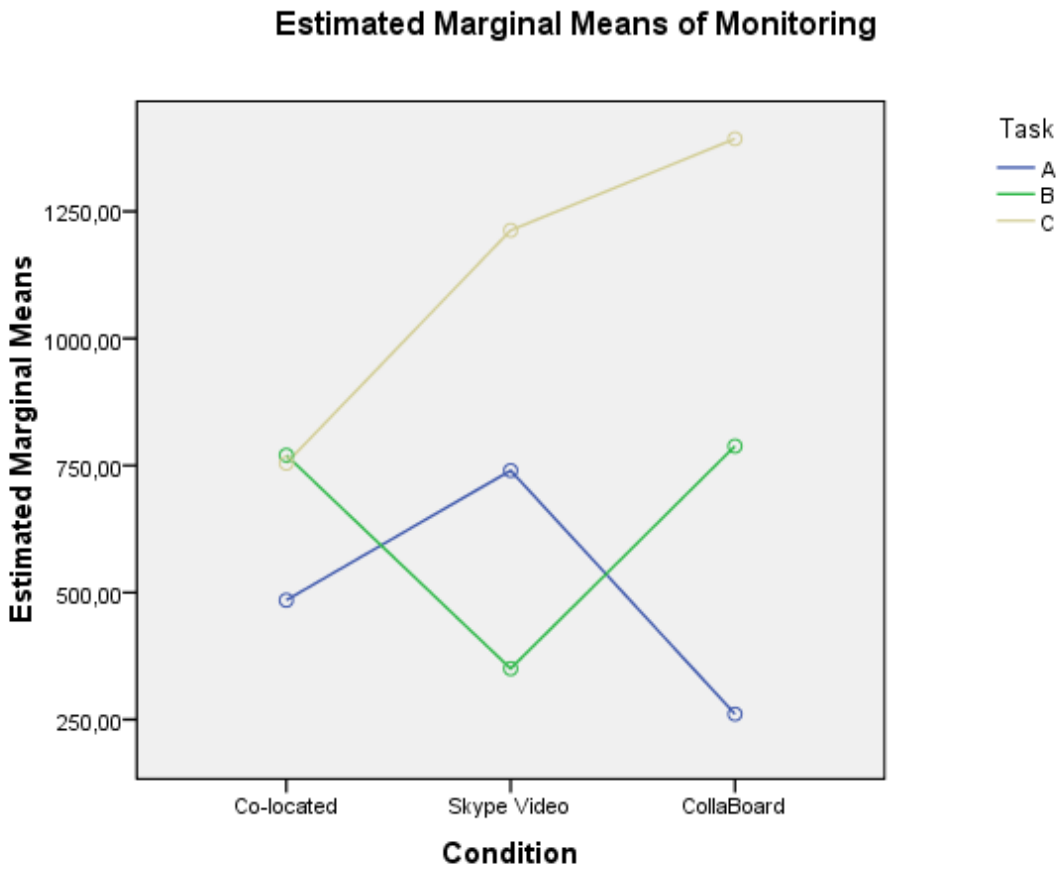

Figure 12: Graph for Monitoring

4.2.3 Descriptive measures (RQ3-RQ6)

The measures *Looking at task description*, *Sketching*, *Erasing* and *Laughing* is analysed descriptively in the next sections. This means that the same analysis performing ANOVA and regressions will be done without noting the significance.

Looking at task description (RQ3)

A two-way ANOVA of variance was conducted to explore the impact of Task and Condition on *Looking at task description*. The main effect for Condition $F(2,18) = 1.54$ and had an effect size of 0.15. The main effect for Task $F(2, 18) = 35.98$ and had an effect size of 0.8 and the interaction effect $F(4, 18) = 2.84$ had an effect size of 0.39.

The parameter estimator table, Table 30 and the box-plots, Figure 13 and 14 shows similar values seen in both the primary and the secondary measures. The means for conditions are similar to one another and the means for tasks differs. The same trend is seen in the graph for *Looking at task description* means, Figure 15.

Table 30: Parameter estimators for Looking at task description

Condition	Mean	Standard Deviation	Median	Number of data
Co-located	94.42	81.30	46.09	9
Skype Video	68.48	38.18	65.53	9
CollaBoard	86.86	71.28	66.67	9
Task	Mean	Standard Deviation	Median	Number of data
A	55.17	18.61	54.32	9
B	37.64	9.11	37.59	9
C	156.95	61.49	158.68	9

The Table (Table 30) shows that the means of *Looking at task description* for condition are similar to one another where the Co-located and CollaBoard has a higher mean than Skype Video. The means for the tasks differ more. The mean of Task C is higher than of Task A and B where Task A has a lower mean than Task B.

In Figure 13, the same is seen. The means for the conditions are similar where the spread is bigger for the Co-located Condition than the others. Outliers are seen for Condition 2 and 3.

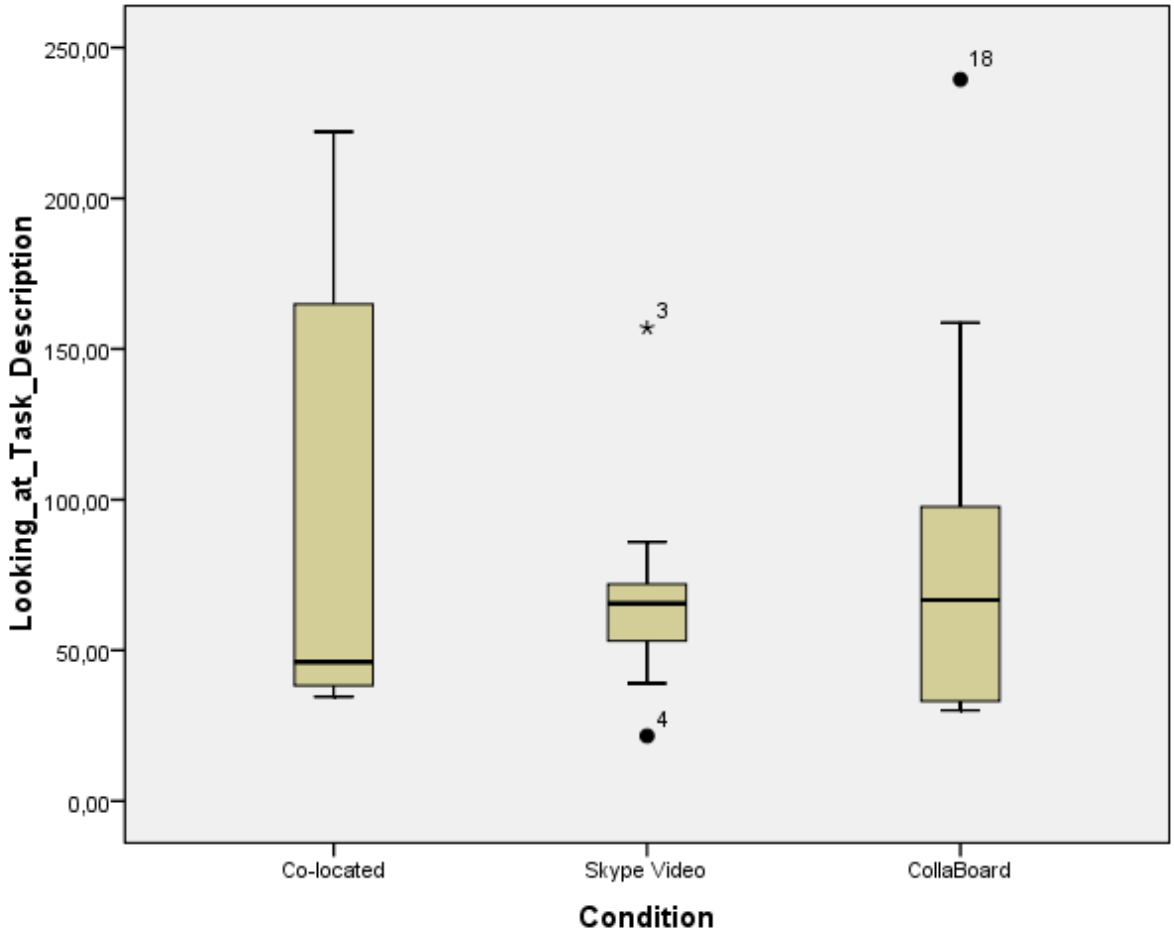

Figure 13: Box-plot for Looking at task description and Condition

In Figure 14, the box-plot for *Looking at task description* and Task is seen. Again, the means for Task A and B are similar but the means for Task C are higher. The spread for Task B is smaller and the spread for Task C is bigger.

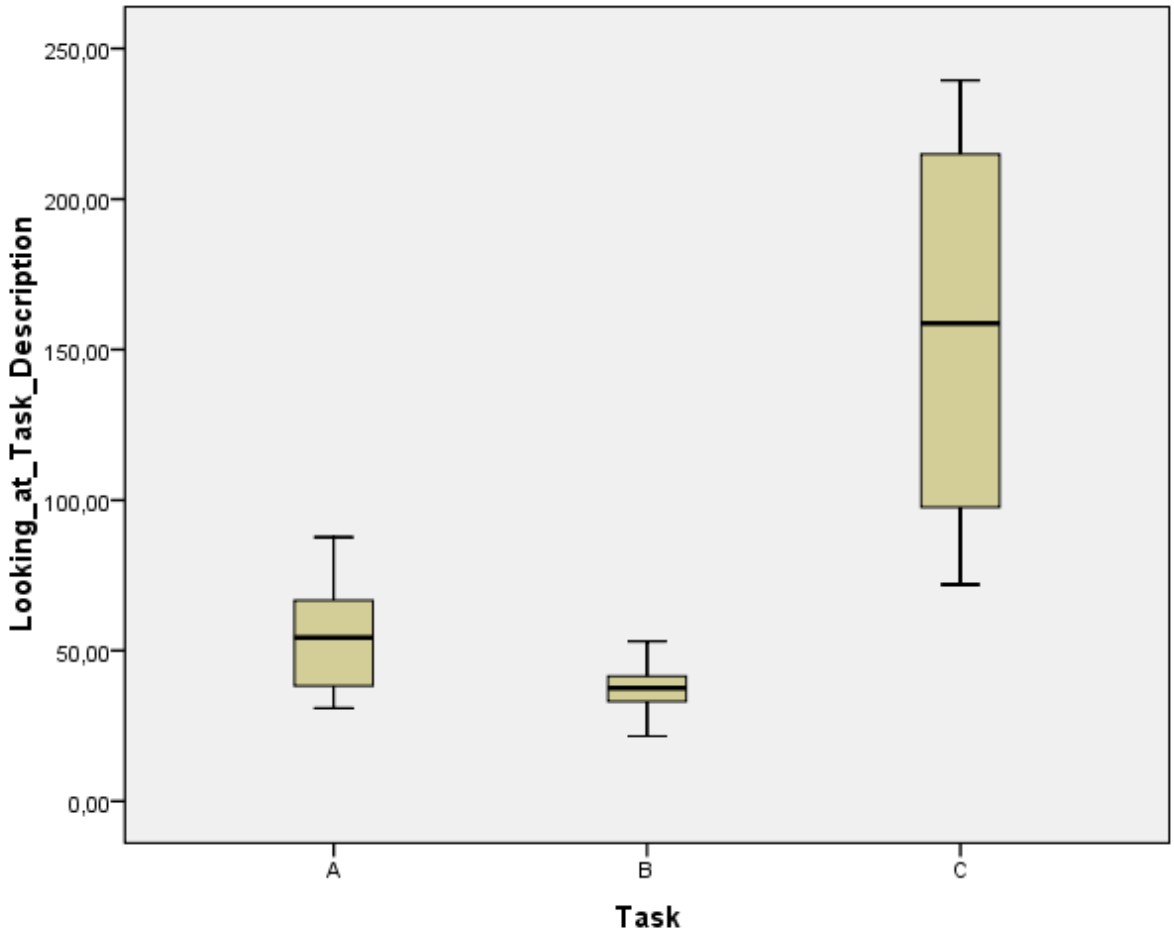

Figure 14: Box-plot for Looking at task description and Task

In Figure 15, the marginal means for *Looking at task description* is seen. Condition is seen on the x-axis and Task is colour-coded. Again, Task C differs from Task A and B.

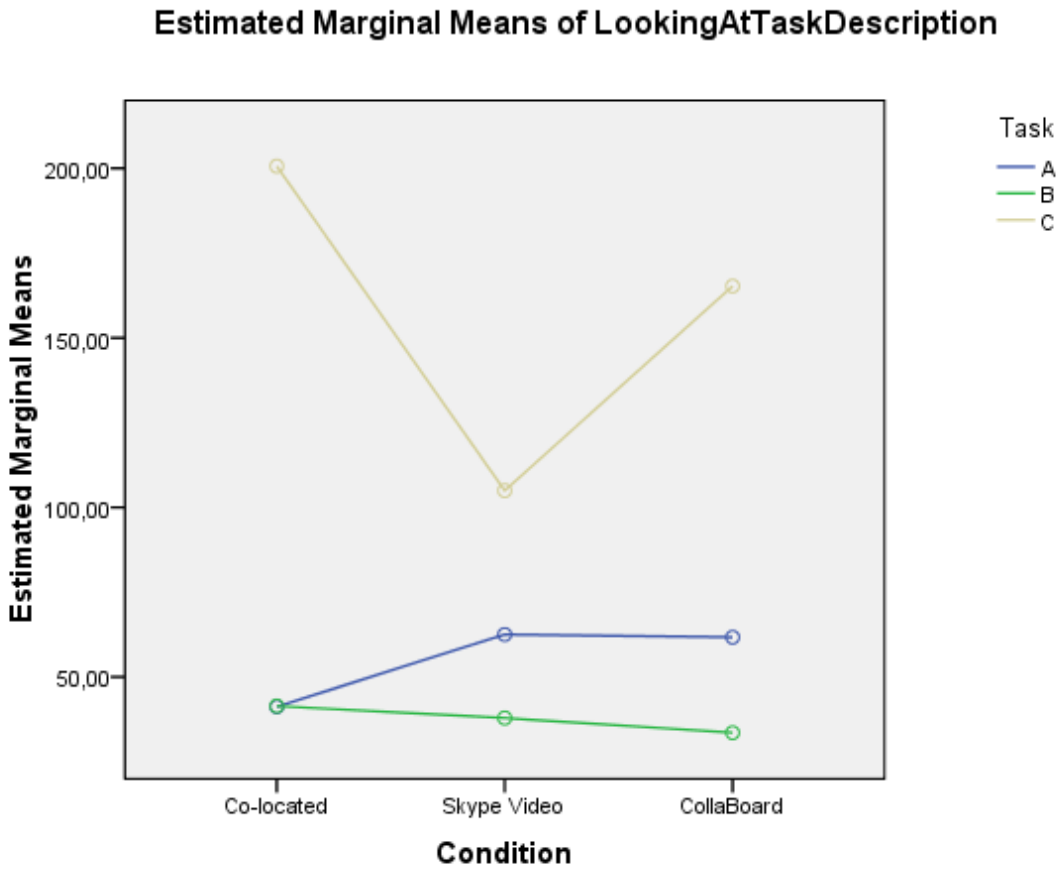

Figure 15: Graph for Looking at task description

Sketching (RQ4)
A two-way ANOVA of variance was done to explore the impact of Condition and Task on *Sketching* time. The main effect for Condition $F(2, 18) = 0.12$ had an effect size of 0.01 and the main effect for Task $F(2, 18) = 10.34$ had an effect size of 0.54. The interaction effect $F(4, 18) = 0.16$ had an effect size of 0.04.

The parameter estimators, Table 31, and box-plots, Figure 16 and 17, for *Sketching* shows similar values as seen for the other measures. The graph for *Sketching* is seen in Figure 18.

Table 31: Parameter estimators for Sketching

Condition	Mean	Standard Deviation	Median	Number of data
Co-located	191.07	153.18	135.21	9
Skype Video	210.20	135.90	141.93	9
CollaBoard	190.06	78.70	166.30	9
Task	Mean	Standard Deviation	Median	Number of data
A	119.10	32.24	120.09	9
B	153.82	70.78	115.00	9
C	317.92	130.63	284.04	9

In Table 31, the mean *Sketching* across condition are quite similar; Co-located and CollaBoard have a lower means than Skype Video. Mean *Sketching* across task differs more; mean of Task C is higher than of Task A and B; Task A is lower than Task B.

Figure 16 shows the box-plot for *Sketching* and Condition. The means are similar to one another as well as the spread. The whisker for Skype Video is bigger than for the Co-located and CollaBoard Condition. The Co-located Condition has one outlier.

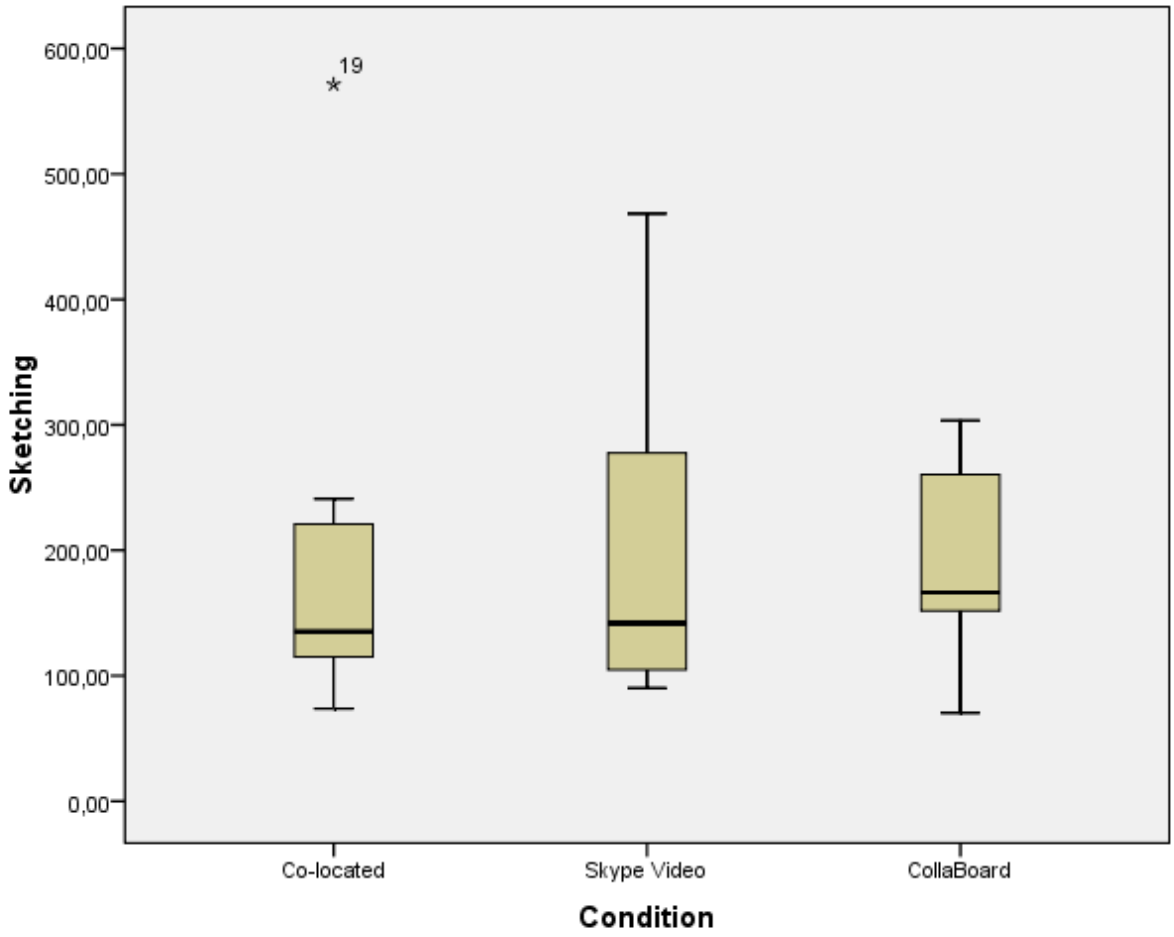

Figure 16: Box-plot for Sketching and Condition

In Figure 17, the means for Task A and B are similar but are higher for Task C. The spread is also bigger for Task C than the others. Task C has one outlier.

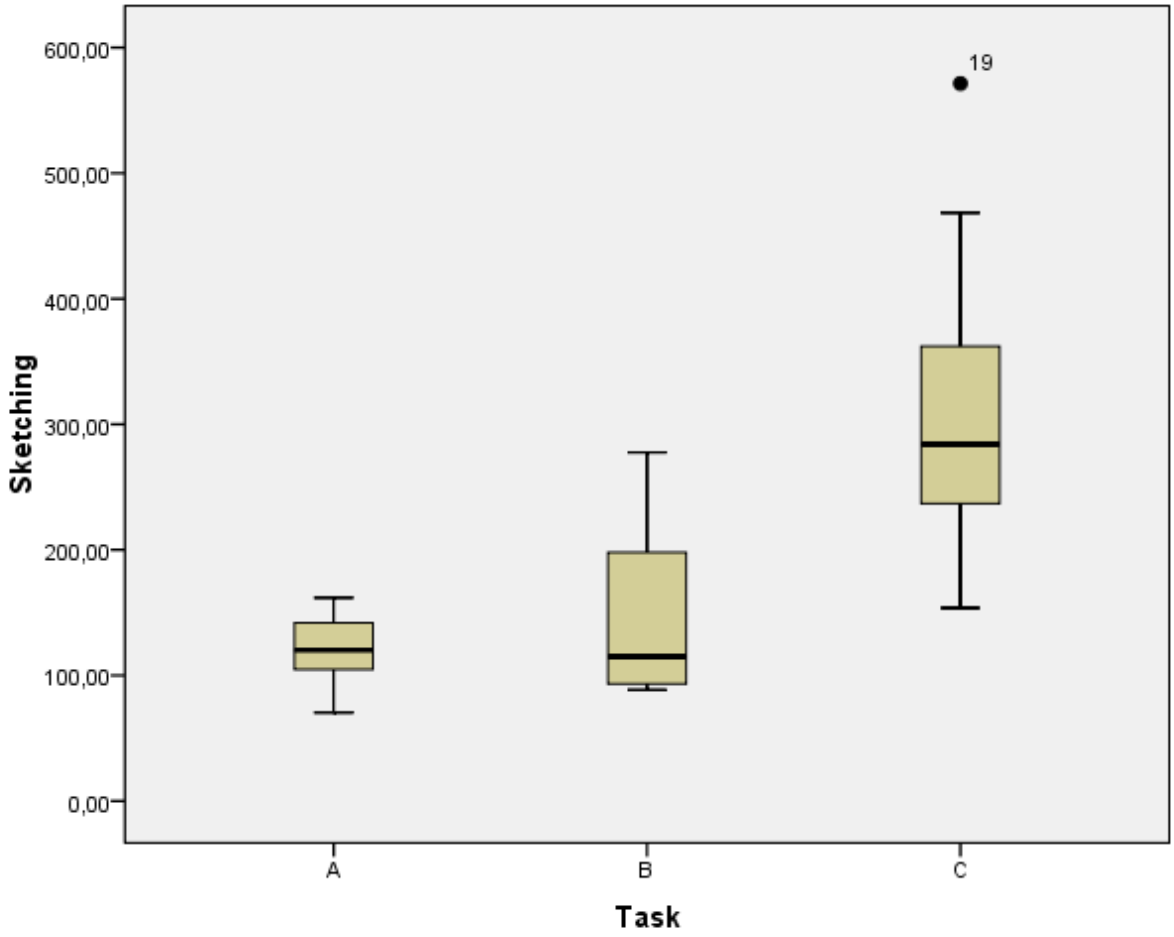

Figure 17: Box-plot for Sketching and Task

Figure 18 shows the graph for marginal means of *Sketching* where Condition is on the x-axis and Task is colour-coded. Again, Task C differs from Task A and B.

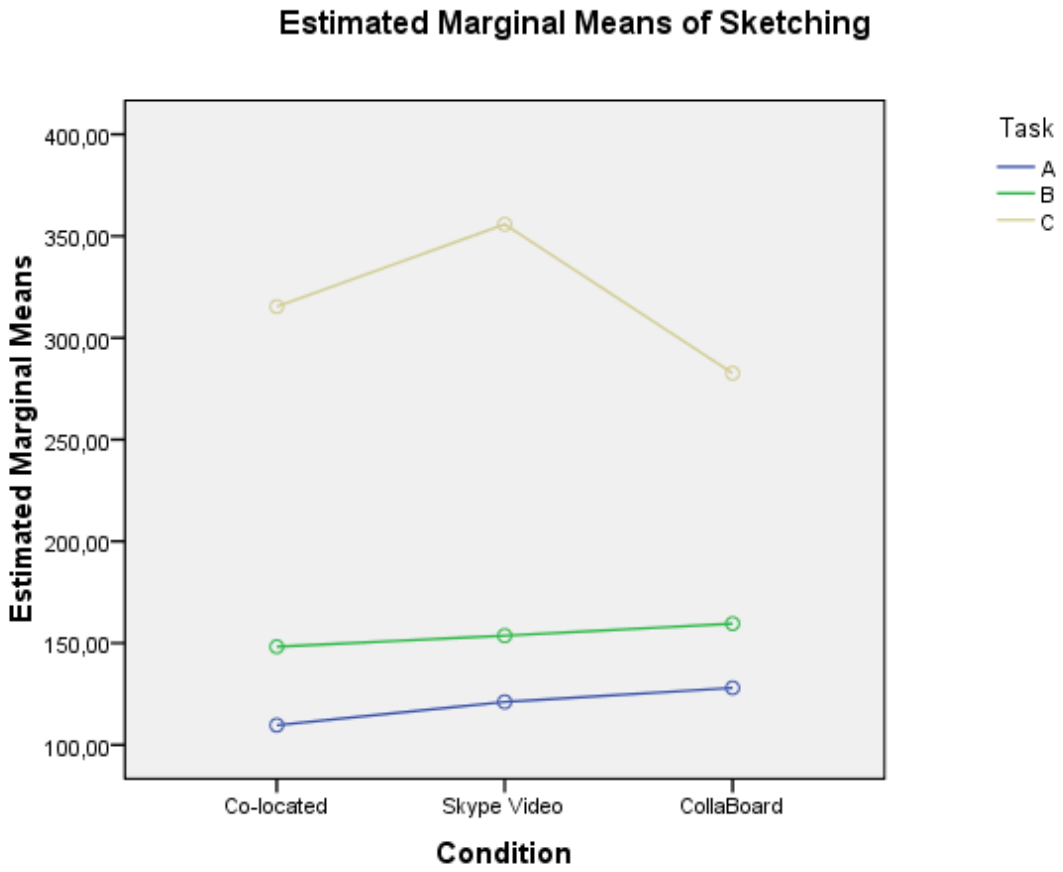

Figure 18: Graph for Sketching

Erasing (RQ5)
A two-way ANOVA of variance was conducted to explore the impact of Task and Condition on *Erasing*. The main effect for Condition $F(2,18) = 0.75$ and had an effect size of 0.01. The main effect for Task $F(2, 18) = 9.04$ and had an effect size of 0.50 and the interaction effect $F(4, 18) = 1.17$ had an effect size of 0.21.

The means for Condition is similar to one another but differ for Task, Table 32 (parameter estimators). The mean size of Task C is bigger than Task B and Task A but Task A has a lower mean than Task B. The same is seen in the box-plots, Figure 19 and 20. This is also seen in the graph for means of *Erasing*, Figure 21.

Table 32: Parameter estimators for Erasing

Condition	Mean	Standard Deviation	Median	Number of data
Co-located	37.43	32.95	54.00	9
Skype Video	35.01	40.81	21.51	9
CollaBoard	40.80	49.50	29.92	9
Task	Mean	Standard Deviation	Median	Number of data
A	12.40	9.89	18.86	9
B	27.11	30.41	12.06	9
C	73.74	43.48	67.34	9

In Table 32, the means of *Erasing* for condition are similar to one another were the Co-located and CollaBoard has a higher mean than Skype Video. The means for the tasks differ more. The mean of Task C is higher than of Task A and B were Task A has a lower mean than Task B.

In Figure 19, the box-plots for *Erasing* and Condition is seen. The means for conditions are similar. Condition 1 and 2 has outliers.

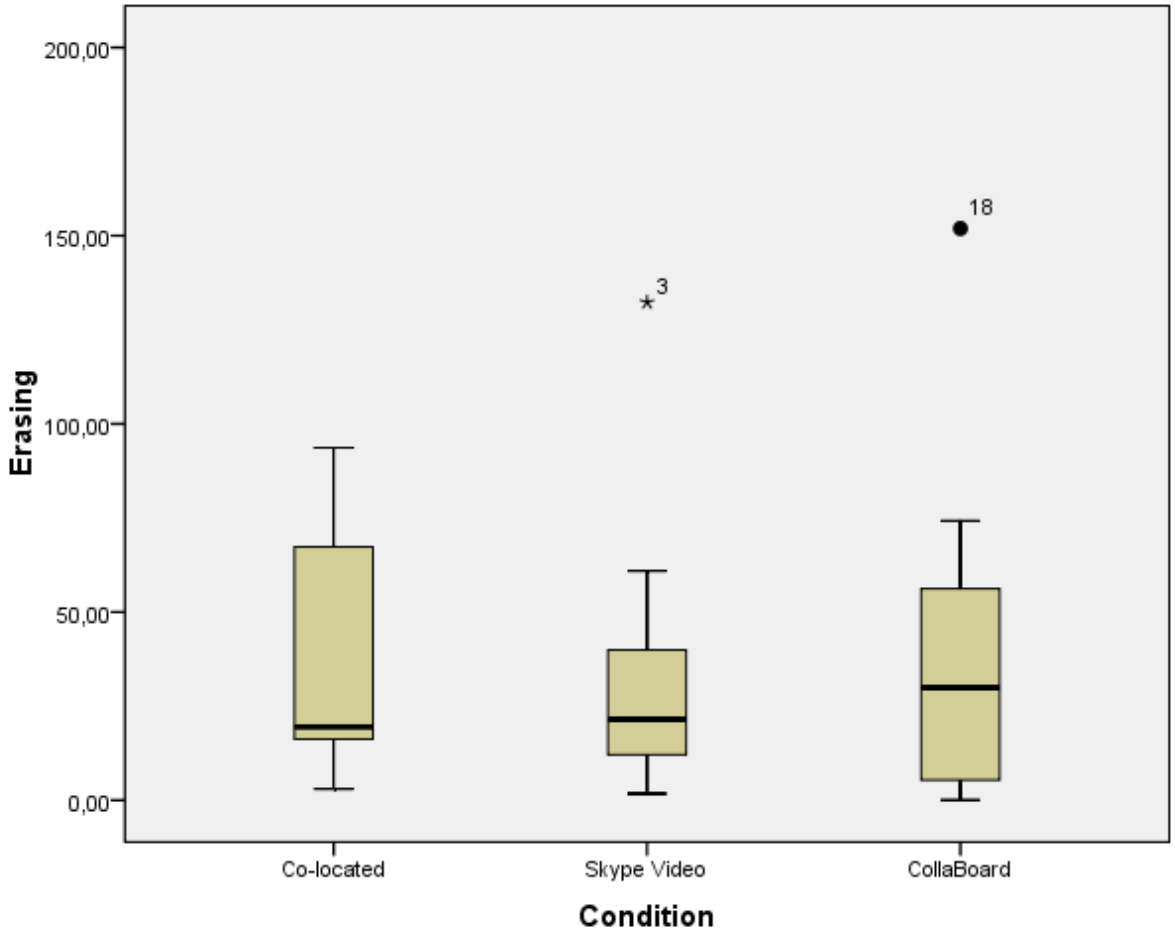

Figure 19: Box-plot for Erasing and Condition

Figure 20, shows the means, medians and whiskers for *Erasing* and Task. It is seen that Task A has a higher mean then Task B and that Task C has a higher mean than both Task A and B. Task B and C has outliers.

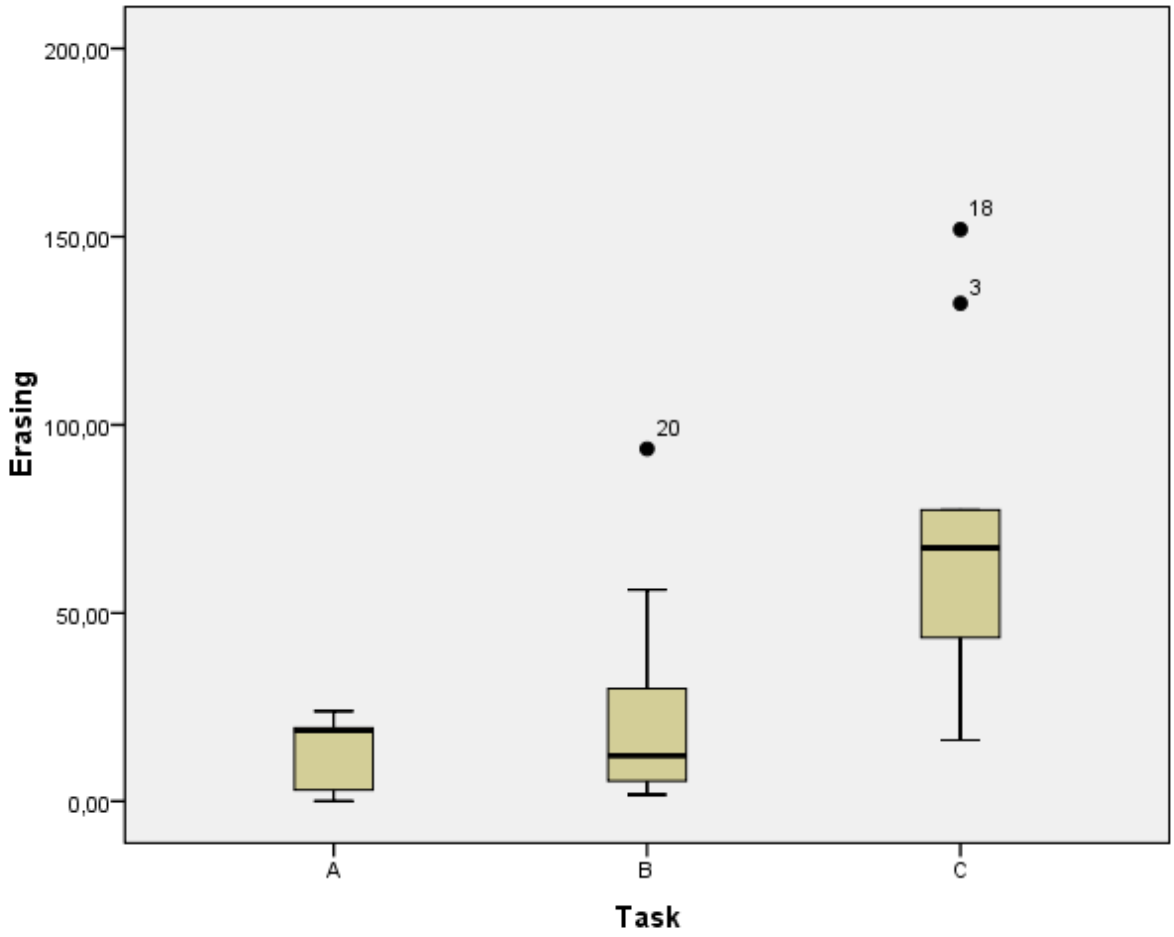

Figure 20: Box-plot for Erasing and Task

The graph for marginal means of *Erasing* is seen in Figure 21, Condition is on the x-axis and Task is colour-coded. Again, Task C differs from Task A and B.

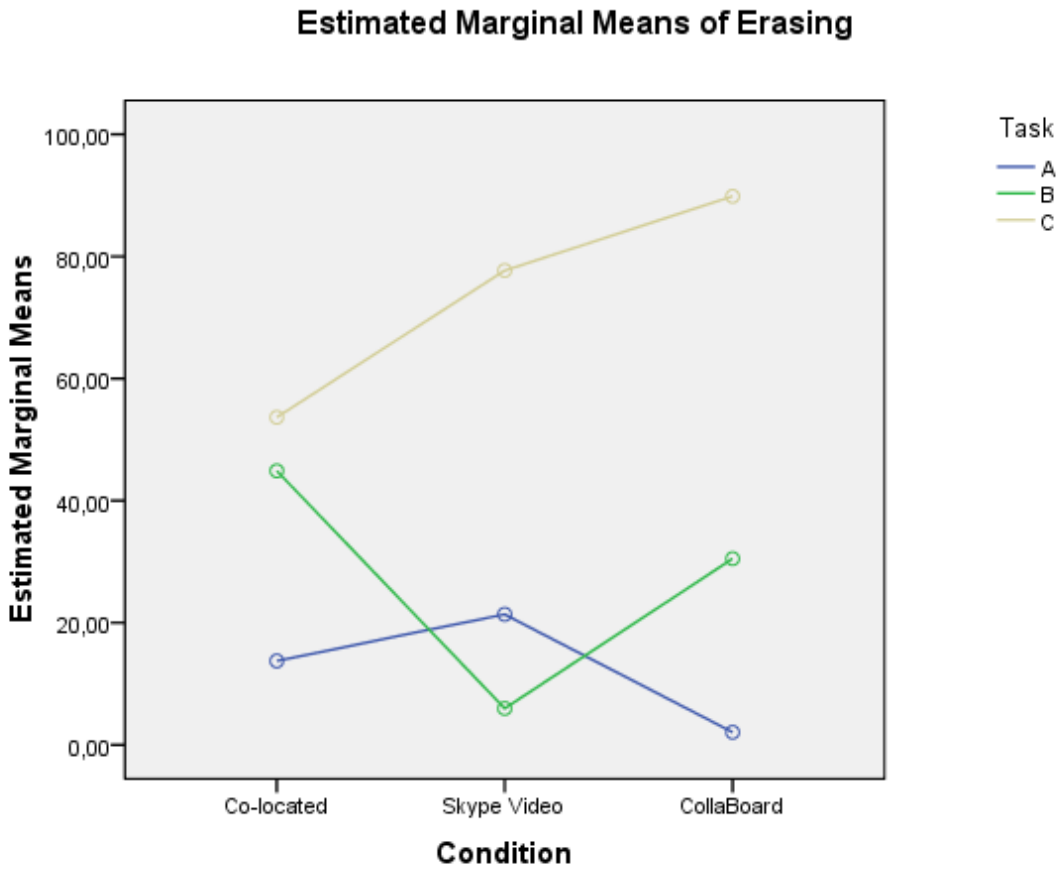

Figure 21: Graph for Erasing

Laughing (RQ6)
The Co-located condition has a higher Poison Regression coefficient (B = 0.10, see Table 33) on *Laughing* than CollaBoard (reference) and lower than for the Skype Video condition (B = -0.11). Task A which has a lower coefficient (B = -1.60) on *Laughing* than Task B (B = -0.42) compared to Task C. Table 32 shows the means for *Laughing* were for Condition the values are similar but differ for Task. Here Task C has a higher mean (12.67) than Task B and A were Task B (6.11) has a higher mean than Task A (2.67).

The same is seen in the parameter estimators, Table 34, the box-plots, Figure 22 and 23 and the graph, Figure 24.

Table 33: Poison Regression coefficients for Laughing

Main effect/ Interaction effect (Condition * Task)	Poison Regression coefficient 2 decimals
Co-located	0.10
Skype Video	-0.11
CollaBoard	0[1]
Task A	-1.69
Task B	-0.42
Task C	0[1]
Co-located * Task A	0.52
Co-located * Task B	-0.92
Co-located * Task C	0[1]
Skype Video * Task A	-0.45
Skype Video * Task B	-0.16
Skype Video * Task C	0[1]
CollaBoard * Task A	0[1]
CollaBoard * Task B	0[1]
CollaBoard * Task C	0[1]

0[1]. Set to zero because the parameter is a reference parameter

The Table (Table 33) shows the Poison Regression coefficient for *Laughing* where the CollaBoard condition and Task C is set to be the reference parameter. Skype Video has a lower coefficient of *Laughing* than the reference parameter and the Co-located Condition has a higher coefficient than the reference. Task A and B has lower coefficient than Task C, were Task A has the lowest. The correlation of interaction effects is also seen.

Table 34: Parameter estimators for Laughing

Condition	Mean	Standard Deviation	Median	Number of data
Co-located	7.33	6.65	5.00	9
Skype Video	6.33	4.62	6.00	9
CollaBoard	7.78	6.99	6.00	9
Task	**Mean**	**Standard Deviation**	**Median**	**Number of data**
A	2.67	6.48	3.00	9
B	6.11	5.32	6.00	9
C	12.67	5.56	13.00	9

In the Table (Table 34) the means of *Laughing* for condition are similar to one another where the Co-located and CollaBoard has a lower mean than Skype Video. The means for the tasks differ more. The mean of Task C is higher than of Task A and B were Task A has a lower mean than Task B.

In Figure 22, the box-plot for *Laughing* and Condition is seen. The means of Condition 1, 2 and 3 are similar where the CollaBoard condition has a bigger spread. One outlier is seen in Condition 1.

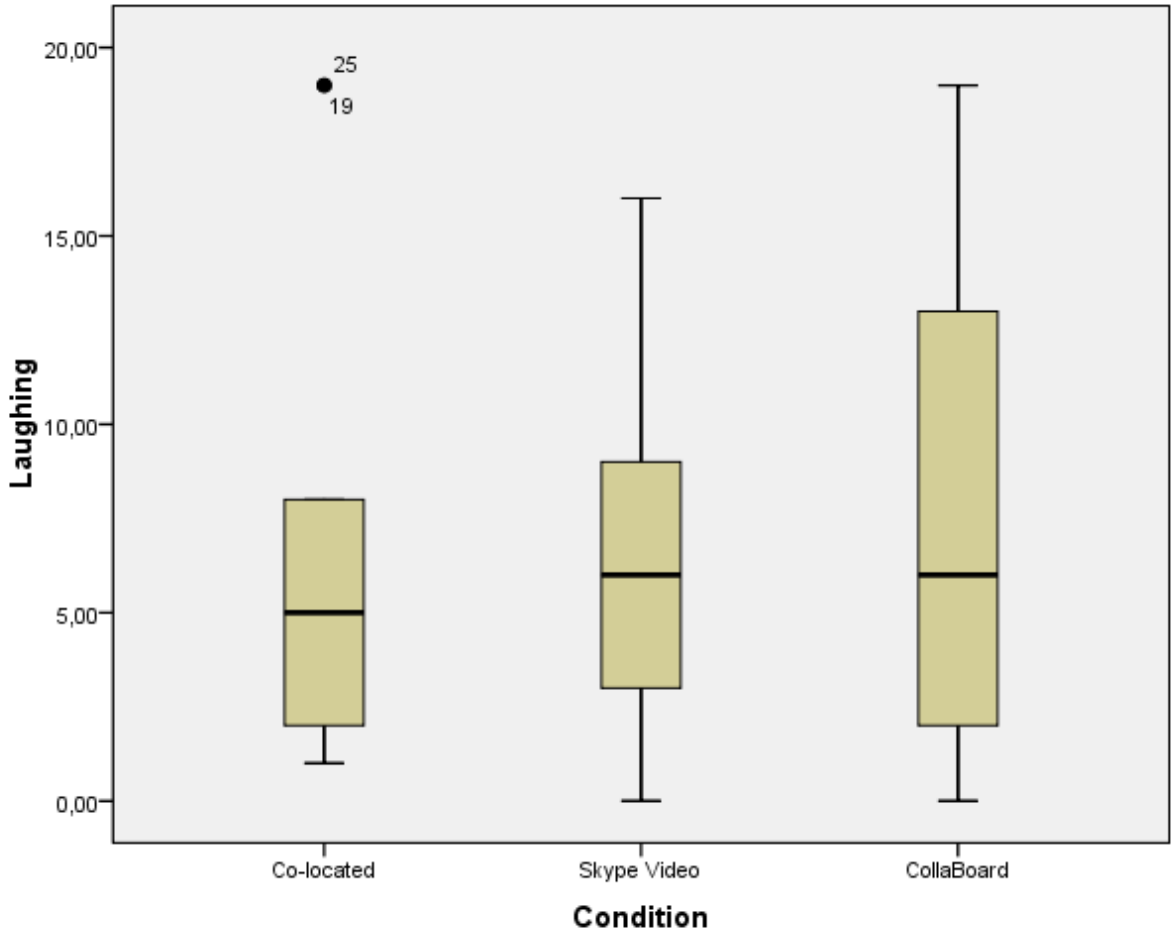

Figure 22: Box-plot for Laughing and Condition

In Figure 23, the box-plot for *Laughing* and Task is seen. The medians, means and whiskers are seen. Task C differs from Task A and B, where the means for Task B are bigger than Task A. The spread of Task C is bigger than for Task A and B. There is one outlier for Task B.

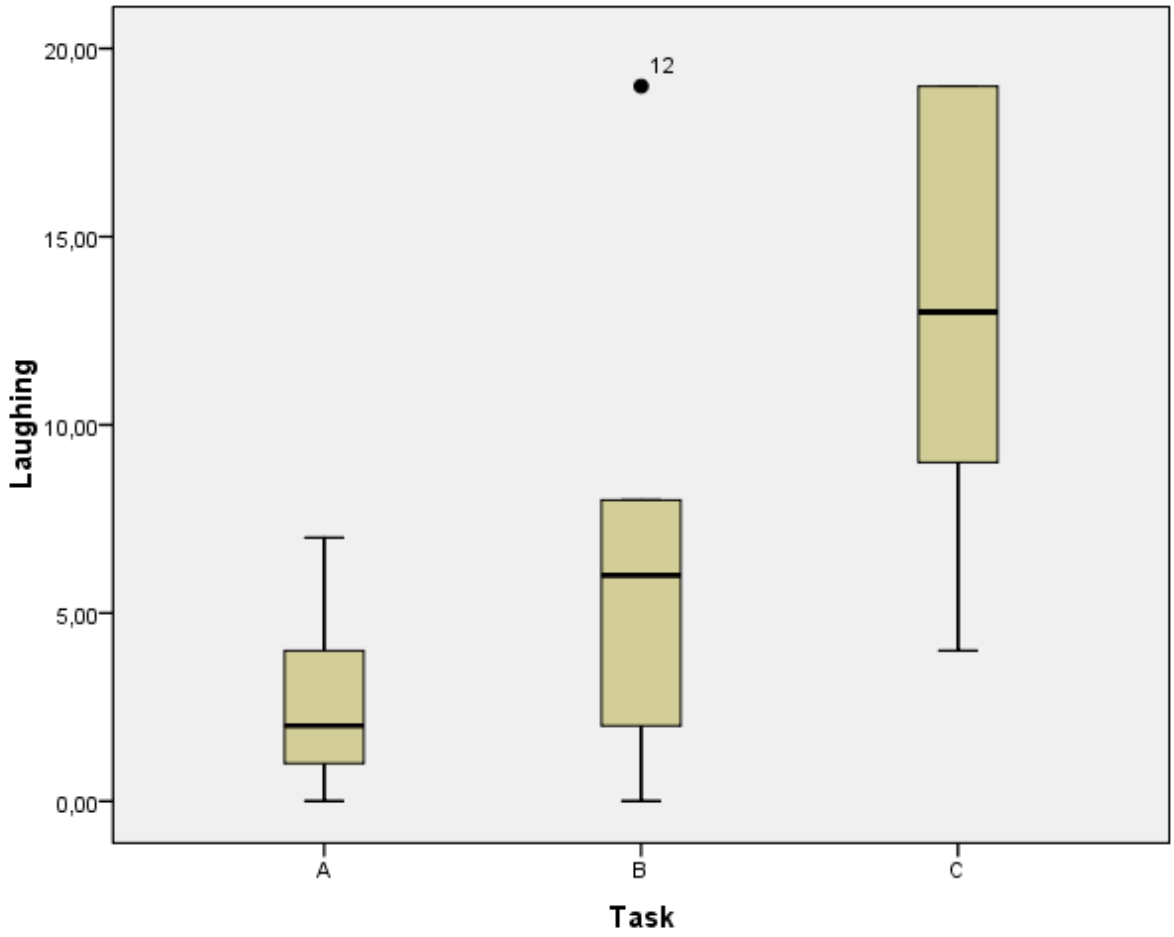

Figure 23: Box-plot for Laughing and Task

In Figure 24, the graph for estimated marginal means of *Laughing* is seen. Task C differs from Task A and B. And there is some difference seen between Task A and B. Task is colour-coded and condition is seen on the x-axis.

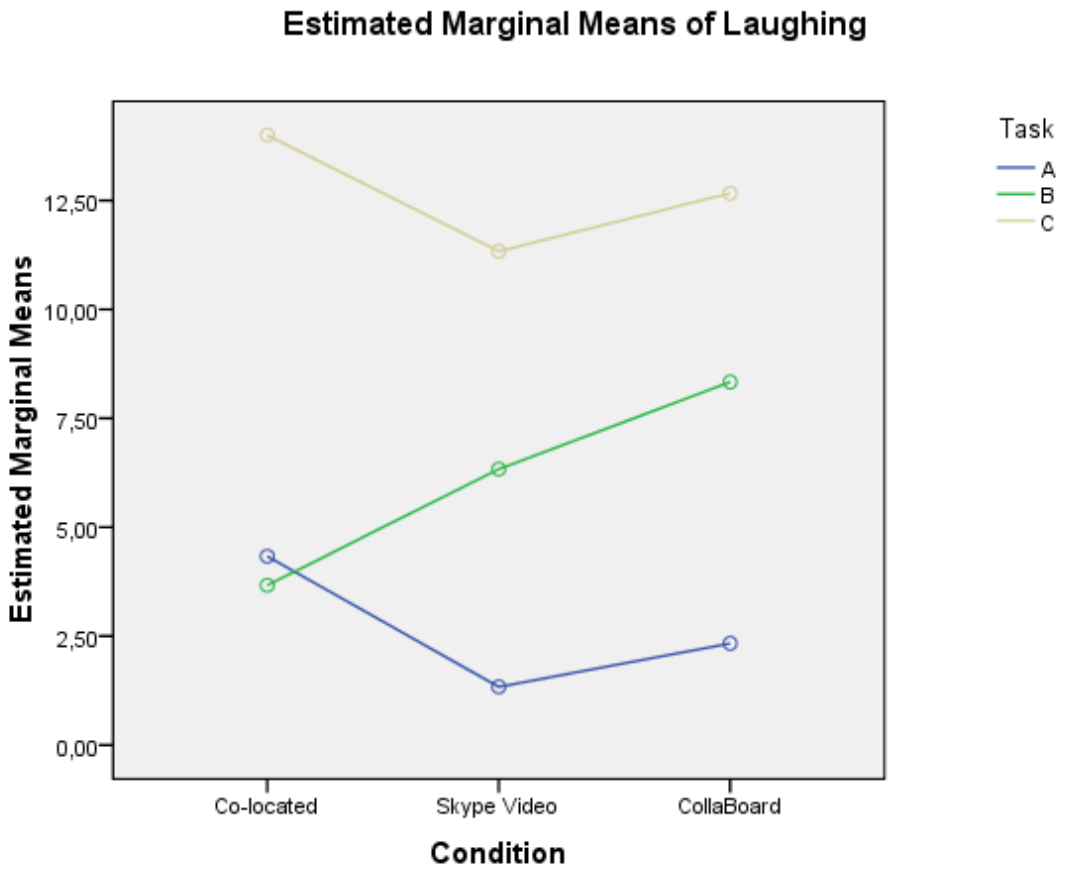

Figure 24: Graph for Laughing

4.3 Qualitative data – *Task process* (RQ7)

A qualitative analysis was done in order to see if trends could be found in the action-over-time-graphs, see an example of the graph in Figure 25 (all graphs can be seen in Appendix V) to describe the *Task process*. This was done in two steps, first the number of action-block changes were calculated in a frequency analysis and then a trend analysis was done in order to see if there were trends in the order of the action changes, the participant behaviour or in the sizes of the action-blocks.

Figure 25, shows an example of the action-over-time-graphs. The graph shows study 1 for participant 1 and 2 in the Co-located Condition. A time axis with seconds as units is seen in the top of the graph. The first row in the graph, the pink one, shows *Monitoring* for participant 1. The second line is for *Erasing*, the third *Sketching* and the fourth *Looking at task description*. The latter two are for *Speaking* and *Laughing*.

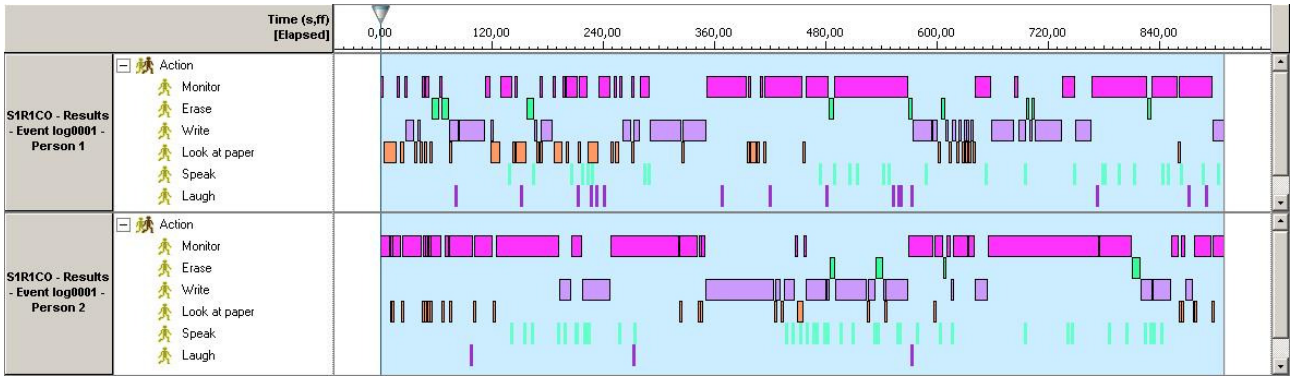

Figure 25: Action-over-time-graph

4.3.1. Frequency analysis

In the frequency analysis the action changes were counted to see if there are differences in Conditions and/or Tasks. The group numbers were also counted.

In Table 35, the differences in Conditions in the action changes can be seen. CollaBoard has a higher value on *Looking at task description* and *Monitoring* - action change (N = 260) while the Co-located and Skype-video has similar values (Co-located: N = 218, Skype Video: N = 200). In *Monitoring* and *Sketching* Skype Video and CollaBoard has a higher value than the Co-located condition (N = 129), where the Skype Video condition (N = 256) is higher than the CollaBoard value (N = 193). CollaBoard also has a higher value than the others for the *Looking at task description* and *Sketching* action change (Co-located: N = 84, Skype Video: N = 77 and CollaBoard: N = 107). The other action changes are similar to one another.

Table 35: Number of action changes for Condition

Condition	**Looking at task description and Monitoring**	**Monitoring and Sketching**	**Looking at task description and Sketching**	**Erasing and Monitoring**	**Erasing and Sketching**	**Erasing and Looking at task description**
Co-located	218	129	84	36	21	1
Skype Video	200	256	77	47	20	7
CollaBoard	260	193	107	49	21	5

The Table (Table 35) shows the number of action changes for the different conditions: Co-located, Skype Video and CollaBoard.

The task difference on action changes can be seen in Table 36. Generally Task A has a higher value than the others which has to do with the time spent on the tasks. The time spent for Task A is three times higher than for Task D. The time spent for Task C is two times higher than for Task D. If the scores are recalculated with basis on that A is three times higher than D and that C is two times higher than D a new Table is given, Table 37.

From the new Table values it can be seen that the action change *Looking at task description* and *Monitoring* is higher for Task A (163.00) than both B (78.50) and C (119.30). Task A also has a higher value of *Monitoring* and *Sketching* per time unit (Task A: 105 in comparison to Task B: 92.00 and Task C: 96.30) and a higher number of *Looking at task description* and *Sketching* (Task A: 80.00, Task B: 12.00 and Task C: 54.67). For *Erasing* and *Monitoring* Task B and C has a higher value than Task A (Task A: 15, Task B: 21.50 and Task C: 24.67). In *Erasing* and *Sketching* Task C had the highest value (Task A: 9.00, Task B: 6.00 and Task C: 13.67).

Table 36: Number of action changes for Task

Task	**Looking at task description and Monitoring**	**Monitoring and Sketching**	**Looking at task description and Sketching**	**Erasing and Monitoring**	**Erasing and Sketching**	**Erasing and Looking at task description**
A	163	105	80	15	9	2
B	157	184	24	43	12	0
C	358	289	164	74	41	11

The Table (Table 36) shows the number of action changes for the different Tasks A, B and C. It is seen that Task C has a higher number of action changes than Task A and B which can be dependent on Time on task.

Table 37: Number of action changes per time unit

Task	**Looking at task description and Monitoring**	**Monitoring and Sketching**	**Looking at task description and Sketching**	**Erasing and Monitoring**	**Erasing and Sketching**	**Erasing and Looking at task description**
A	163.00	105.00	80.00	15.00	9.00	2.00
B	78.50	92.00	12.00	21.50	6.00	0.00
C	119.30	96.30	54.67	24.67	13.67	3.67

The Table (Table 37) shows the number of action changes for the different Tasks A, B and C per time unit. Task A has the highest number of *Looking at task description* and *Monitoring*, *Monitoring* and *Sketching*, *Looking at task description* and *Sketching* while Task B and C has a higher number of *Erasing* and *Monitoring*. Task C has the highest number of *Erasing* and *Sketching* per time unit.

The differences in action changes for the groups are seen in Table 38. The highlighted numbers are those that are higher than the other ones, compare these to the total number in Table 39. Group number three has the highest number of *Monitoring* and *Sketching*, *Erasing* and *Monitoring* (EM), *Erasing* and *Sketching* and *Erasing* and *Looking at task description* action changes. A high value of the action change *Looking at task description* and *Monitoring* can be seen for Group number 7 (N = 105) and 9 (N = 116). Group number 7 also has the lowest completion time on the tasks, 17.38 minutes. The Group that took the longest time on completing the tasks was Group number 2, 34.44 minutes. A high value for EM can be seen for Group Number 6 (N = 50).

Table 38: Number of action changes per Group

Group number	**Looking at task description and Monitoring**	**Monitoring and Sketching**	**Looking at task description and Sketching**	**Erasing and Monitoring**	**Erasing and Sketching**	**Erasing and Looking at task description**
1*	69	55	26	11	7	*0*
2	84	62	*15*	16	7	1
3	*43*	**94**	33	**29**	**13**	**6**
4	68	56	25	*5*	6	*0*
5*	76	*45*	28	6	*2*	*0*
6	59	46	**50**	17	6	2
7*	**105**	61	26	11	5	*0*
8	58	86	31	14	8	2
9	**116**	73	34	23	8	2

* = Finished all tasks

Table 38, shows the number of action changes for each of the groups. The time spent on tasks can be seen in the last column. The highest numbers are highlighted (made bold) also the lowest are highlighted (made italic). The lowest time for completing the tasks was 17.38 minutes and was made by Group number 7, see full table in Appendix VI.

Table 39: Total number of action changes

Values	**Looking at task description and Monitoring**	**Monitoring and Sketching**	**Looking at task description and Sketching**	**Erasing and Monitoring**	**Erasing and Sketching**	**Erasing and Looking at task description**
Total sum	678	578	268	132	62	13
Mean	75.30	64.20	29.78	14.67	6.89	1.44

This Table (Table 39) shows the total sum of actions changes as well as the means for them. The highlighted number in Table 38 is higher than the means in this Table.

4.3.2 Trend analysis

The action-over-time-graphs were investigated to see if there were any trends in the order of action changes, participant behaviour or the size of the action-blocks. In order to find trends all graphs were examined looking for similarities and differences. Some action changes formed clusters and were repeated in several graphs. These clusters were named and examined further to see if they could say something about the *Task process*. In the beginning of a task participants had a cluster of *Looking at task description*, *Monitoring* and *Sketching* this cluster was named Task solving. When the Task was harder especially on Task C longer time was spent on Looking and *Monitoring*, called Initiation, and after that a period of *Monitoring* and *Sketching*, called Near solution, in combination of *Erasing* or *Monitoring* and *Erasing*, called Fault fixing occurred. The names and what action-block change they represent are shown in Table 40. In Figure 26-30 the action-block changes are exemplified.

Table 40: Action-block changes

Name	Cluster of action-block changes
Initiation	Looking at task description and Monitoring
Task solving	Looking at task description, Monitoring and Sketching
Near solution	Monitoring and Sketching
Fault fixing	Monitoring and Erasing
Conversation	Speaking and Laughing

Table 40 stated the names of the action-block changes and what changes they represent.

In Figure 26 the Initiation is exemplified. It is defined as the action-block changes: *Looking at task description* and *Monitoring*.

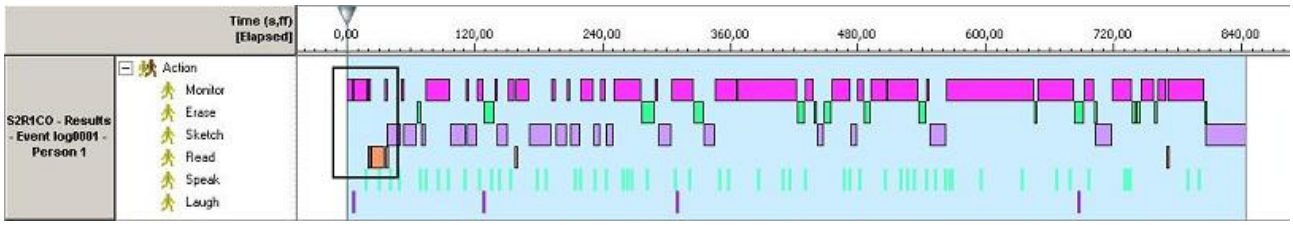

Figure 26: Cluster of action-block changes - Initiation

In Figure 27 three Task solving clusters are seen. Task solving is defined as action-blocks of *Looking at task description, Monitoring* and *Sketching*.

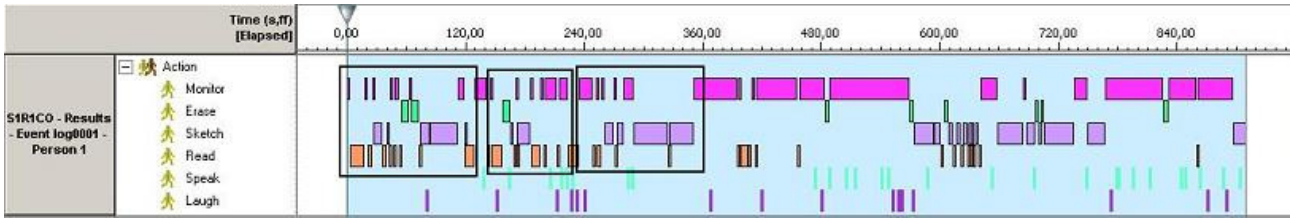

Figure 27: Cluster of action-block changes - Task solving

Figure 28 shows three clusters of Near solution. Near solution is defined as an action-block changes including *Monitoring* and *Sketching*.

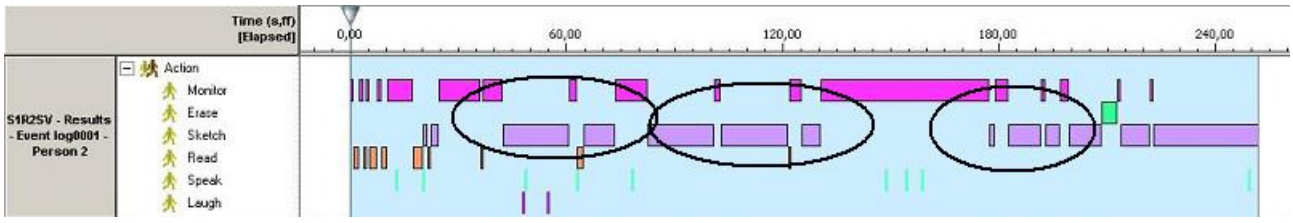

Figure 28: Cluster of action-block changes – Near solution

The Figure (Figure 29) exemplifies the action-block changes called Fault fixing which is defined as action-blocks of *Monitoring* and *Erasing*.

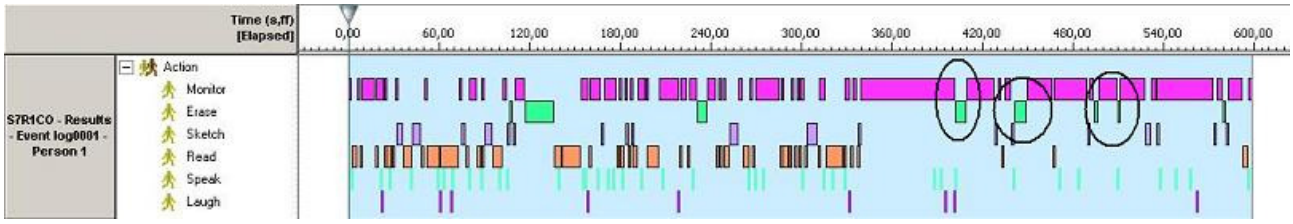

Figure 29: Cluster of action-block changes – Fault fixing

The Figure (Figure 30) shows the action-block changes called Conversation which is defined as the action-blocks of *Speaking* and *Laughing*. The clusters are marked with a circle. In the top graph four conversational clusters are seen and in the bottom there are three.

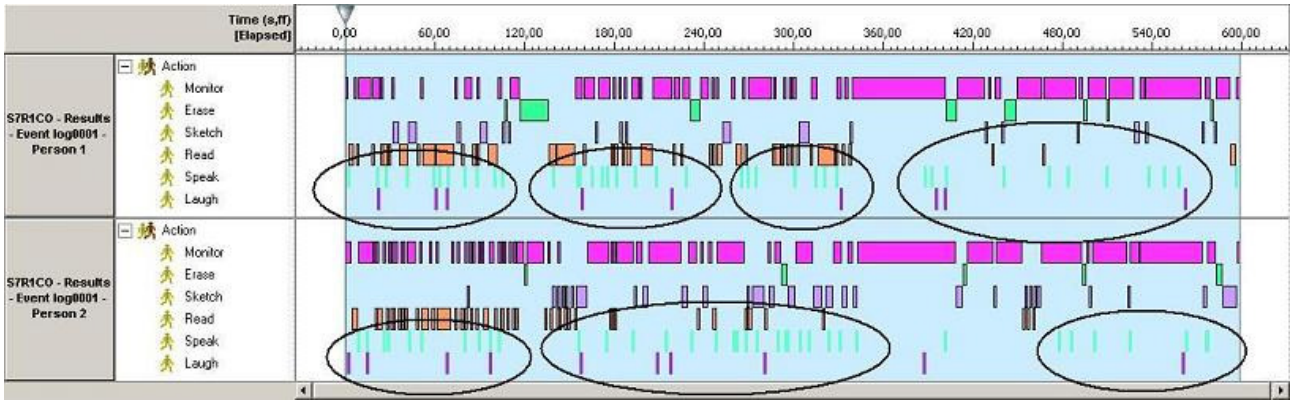

Figure 30: Clusters of action-block changes – Conversation

Task solving and conversation were the most frequent clusters and it was interesting to count them to see if any differences in condition,task or groups could be found. Table 41 shows that the Task Solving was similar in number for the conditions as well as for the tasks. The number of task solving are similar for Task even though the time for the tasks are different. *Laughing* was more frequent in the CollaBoard condition as well as for Task C.

Table 41: Number of action-block changes for Condition and Task.

Condition	Task solving cluster	Conversation cluster	Number of times Laughing
Co-located	31	29	64
Skype Video	26	16	63
CollaBoard	22	30	70
Condition	Task solving cluster	Conversation cluster	Number of times Laughing
A	23	22	62
B	30	20	52
C	26	33	83

The Table (Table 41) shows the number of action-block changes for Task solving and Conversation in the qualitative analysis for conditions and tasks. The number of times *Laughing* is also seen.

More differences can be seen in the numbers for each group. In comparison to the means in Table 42 the number of action-block changes in Conversation are higher for Group 3, 4 and 5 (Group 4: 12, Group 5: 16 and Group 6: 11, were the mean is 8.33). Group 6 showed a lower score on Conversation (2 clusters). Group 1, 3 and 8 had a higher number of times *Laughing* (Group 1: 32, Group 3: 33 and Group 8: 27) than the others were one Group 5 had the lowest 5 laughs. The mean for number of laughs is 21.89. The total number of action-block changes can be seen in Table 43.

Table 42: Number of action-block changes for Group

Group number	Task solving cluster	Conversation cluster	Laughing
1	7	9	**32**
2	9	6	21
3	7	**12**	**33**
4	8	**16**	22
5	8	**11**	*4*
6	7	*2*	23
7	11	9	26
8	12	5	**27**
9	10	5	9

The Table (Table 42) shows the number of action-block changes for Task solving and Conversation is seen for the 9 groups. The number of times *Laughing* is also seen. High numbers are highlighted and small numbers are made italic.

Table 43: Total number of action-block changes

Variable	Task solving cluster	Conversation cluster	Laughing
Total sum	79	75	197
Mean	8.78	8.33	21.89

Table 43 shows the total sum and the mean of the number of action-black changes and *Laughing* divided over nine groups.

Also an descriptive analysis were made from additional information about the *Task process* that was seen in the graphs. The full tables are seen in Appendix VI. The descriptives were divided into occurrences and is seen in Tables 44-46. High number for participants that talked frequently can be seen in Skype Video (N = 11, were the total number of people talking are 20, Table 45). Exemples of a frequent Talker and Monitorer is seen in Figure 31. Skype Video also has the highest value of specific order of clusters (N = 15, were the total is 27). For CollaBoard the specific order of clusters are 7 (For Co-located N = 5). A slightly higher number of specific order of clusters is seen for Task C, Table 46 (Task C: N = 12, Task A: N = 9 and Task B: N = 6). Task A and B has double the amount of participants that talk frequently than Task C (Task A and B: N = 8 and Task C: N = 4).

Table 44: Additional descriptive information from action-over-time-graphs

Additional descriptive information from action-over-time-graphs	How measured
Participant behaviour	Some participant talked, wrote, looked at task description or monitored frequently
Size of action-blocks in clusters	The time spent on action-blocks was seen to be were short in some clusters
Cluster orders	Some participants had a specific order of clusters followed by another than going back to the first etcetera.

Additional descriptive information found in action-over-time-graphs and how it was measured is offered in the Table (Table 44).

Figure 31 shows an example of the additional descriptive information found in the action-over-time-graphs. In the top graph a square is formed over the talking blocks in the graph, called a Talker since they are frequent. The bottom graph shows a Monitorer which is marked by a circle.

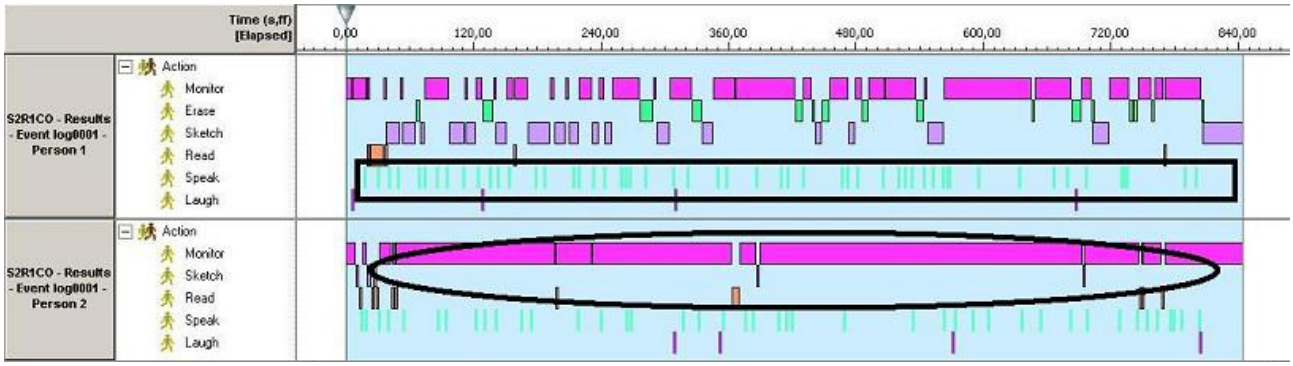

Figure 31: An example of additional descriptive information in the action-over-time-graphs: A Talker and a Monitorer

Table 45: Participant behaviour for Condition and Task

Condition	**Participant talks frequently**	**Participant writes frequently**	**Participant looks at task description frequently**	**Participant laughs frequently**	**Participant monitors frequently**
Co-located	4	0	1	0	2
Skype Video	11	1	0	0	2
CollaBoard	5	1	0	1	2
Task	**Participant talks frequently**	**Participant writes frequently**	**Participant looks at task description frequently**	**Participant laughs frequently**	**Participant monitors frequently**
A	**8**	0	0	0	2
B	**8**	2	0	0	2
C	4	0	1	1	2
Total number	20	2	1	1	6

The result from the descriptive analysis can be seen in the Table (Table 45) were participants that talked frequently were seen in Skype Video and in Task A and B. The total amount number of occurrences is seen in the bottom of the Table.

Table 46: Size of action-blocks in clusters and cluster orders for Condition and Task

Condition	**Short time action-blocks in cluster**	**Alternating Task solving clusters**	**Specific order of clusters**
Co-located	0	6	5
Skype Video	2	0	15
CollaBoard	4	0	7
Task	**Short time action-blocks in cluster**	**Alternating Task solving clusters**	**Specific order of clusters**
A	3	4	9
B	3	0	6
C	0	2	**12**
Total number	6	6	27

The Table (Table 46) shows the number of short time action-blocks in clusters, alternating task solving and specific order of clusters. A high number of specific order of clusters can be seen for Skype Video and for Task C. The total amount number of occurrences be seen in the bottom of the Table.

5 Analysis and Discussion of results

The results from the quantitative (section 5.1) and the qualitative analysis (section 5.2) are analysed and discussed in this chapter.

5.1 Quantitative results (RQ1 and RQ2)

The results from the quantitative analysis are summarised in Table 47. There was no statistical significance for condition in either of the two measures. Significance was seen for Task. However, for *Speaking* this was due to Time on task. In *Monitoring* the significance was due to both the time and the task itself and was seen between the easy and the hard task.

Table 47: Summary of quantitative results

Measure	Statistically significant difference in mean for Condition	Statistically significant difference in mean for Task	Significance due to
Speaking – Primary measure	No	Yes	Time
Monitoring – Secondary measure	No	Yes	Time and Task

In Table 47, the results from the quantitative analysis are seen.

The box-plots for *Speaking* and *Monitoring* showed that there were a large spread for the measures and the Condition. The same was seen for the other measures in the descriptive data. This could mean that more observations are needed in order for a significance to be seen. It could also mean that the experiment set-up was made in a way that no difference in Condition could be seen. Maybe the differences in the conditions were small in relation to the task, meaning that the conditions did not make it hard or impossible to solve the task. The reason for the task not being solved or being solved with different times had to do with task difficulty not the condition used. In this case the duration of the measures were more effected by the differences in task difficulty than by the conditions. That is the differences in the conditions were too small to effect the task solving process.

The box-plots for Task most often showed that Task A had the most number of occurrences, then Task B and the last Task A. In the graphs as well as the box-plots it was seen that Task A was different from the others. In *Monitoring* it was seen that the statistical significant difference was seen in Task A and C, the easy and the hard task. However in some box-plots it was seen that Task A had a higher mean than Task B. This means that for the harder task the behaviour of the participants regarding the six measures was much different than for the easier tasks. This is not hard to argue for since only 3of the 9 pairs solved the hardest task correctly and when a person does not find a solution for a problem it is possible that he or she acts in another way than in a normal task-solving process.

5.2 Qualitative results (RQ7)

In the qualitative data the *Task process* is investigated. This was done by looking at the action-blocks changes and clusters in the action-over-time-graphs. A summary of were the most action-blocks are seen is presented (Table 48) as well as a summary for action-block clusters (Table 49).

Table 48: A summary of the most action-block changes

The most action-block changes	Condition	Implication
Involving Looking at task description	CollaBoard	More focus is put on Task Description
Monitoring – Sketching	Skype Video	More interactions with the whiteboard are done
The most action-block changes	**Task**	**Implication**
Involving Looking at task description, Monitoring and Sketching	Easy task	More focus on the task and solving it with easier task
Involving erasing	Harder tasks	More errors with harder tasks

In the Table (Table 48) the most action-block changes as stated followed by what condition or task connected to it. The implications of that is also seen.

Table 49: A summary of the action-block clusters

Action-block cluster	Condition	Implication
Task-solving	Co-located	More task-solving focus with support on natural behaviour
Laughing	CollaBoard	Most satisfaction and fun errors happens with CollaBoard
Conversational	CollaBoard and Co-located	Participants focus more on the screen than on talking in Skype Video
Specific clusters	Skype Video	Most structured behaviour
Talking frequently	Skype Video	Talking is part of solving an average task
Action-block cluster	**Task**	**Implication**
Task-solving	Average task	Most focus is put on task-solving in the average task
Laughing	Easy and hard task	More fun with easy and hard task
Conversational clusters	Hard task	More talking with the hard task
Special clusters	Hard task	More structured behaviour is needed to solve the hard task

In Table 49, the action-block clusters that had the most number of occurrences in the qualitative analysis is presented. The condition or task connected to it is also presented as well as the implications.

Combining the two tables it is possible to say something about the *Task process* in each of the conditions and tasks in the experiment. Starting with the conditions the Co-located condition had the most task-solving and conversation clusters which means that a natural flow of talking can be used and that task-solving is in focus.

In the Skype Video condition more *Monitoring* and corrections on the board were done. Also it had the most specific clusters. This means that in Skype Video the most focus is put on the whiteboard which is likely since there is no natural way to follow what happens where in the whiteboard. That

is, the most specific clusters are seen for Skype Video which mean that the participants can work in a structured way without natural interruptions and that task solving in Skype Video needs a structured clustering behaviour. Also the most frequent talking was seen in Skype Video which means that talking frequently is needed or is part of the task solving with Skype Video.

For CollaBoard the most focus is put on the task description. Since in the other conditions focus has been on something else like the whiteboard or the task-solving it is possible to draw the conclusion that focusing on the task description is a characteristic for CollaBoard. Also much Conversational clusters and the most *Laughing* was seen with CollaBoard, which implies that task-solving with CollaBoard gives satisfaction to the users and that much conversational clusters is needed. For the easy task it was seen that most focus was put on *Looking at task description* and the whiteboard which can mean that the easy task is characterised by looking focusing on the whiteboard and the task description. Also much *Laughing* was seen in the easy task which means that an easy task is fun to solve. In the average task the most task-solving was seen. Also the least *Laughing* and conversations was seen for the average task which means that the most focus when solving an average task is on the actual task-solving. The hardest task was characterised by specific clustering, *Erasing*, conversational clusters and *Laughing* which means that for a harder task more focus has to be on structured behaviour and that with a really hard task as this one much *Erasing* is needed. The most *Laughing* was seen here which can be due to that the participants laugh at their mistakes or that they have more fun solving a hard task. Also the most conversational clusters were seen for the hard task.

6 Conclusions and implications

In this last chapter, conclusions from the results are drawn (section 6.1), implications of the study are presented (section 6.2), and future studies are suggested (section 6.3).

6.1 Conclusions

Since computers first came into our society the technology has grown fast as has the research connected to it. However since evaluation naturally comes after making technology, and the technology has been fast growing, some research has been left behind. Computer Supported Collaborate Work has focused on evaluating complex systems in order to improve them. However no universal evaluation method has been found. The literature study, presented in the first part of this thesis, indicates that CSCW research could benefit from a stronger focus on usability and social aspects of complex systems.

The first of this thesis has been to describe and understand previous CSCW research in order to find what measures has not been studied well before. In the literature study it was seen that little research had been done in usability and collective measures and that the most studies had been done in individual measures. This may be surprising, since the focus of CSCW is the study of computer-mediated collaboration and co-operation. A small amount of studies were also seen in remote and co-located systems as well as in using video data. Hence, the second aim of this thesis has been to single out and investigate less-studied measures of CSCW. Usability and collective measures were chosen to be further investigated. To validate this validity of these measures, we applied them on an existing body of experimental data. While the existing data set also included subjective data, the chosen measures were applied on an objective data set, namely video taped observations. The collection of experimental data stemmed from a within-group design experiment involving a eighteen participants. Nine pairs of subjects solved dot-to-dot puzzle problems under three conditions, two of these conditions were remote; one condition was co-located. One of the remote systems tested in the user study was CollaBoard, a new prototype built in Zurich. CollaBoard has a new technology enabling the remote participant to be visible in the working space which makes it interesting to evaluate it in comparison to other conditions. Together with theory of usability and psychology an evaluation method was made making it possible to find measures for the set-up of the user study. The measures found in the evaluation method were tested in the user study in order to answer the driving question:

How can the measures be defined in order to contribute to the evaluation of CSCW systems?

From this driving questions, seven research questions (RQ1-RQ7) was derived, presented in Table 17. In the quantitative as well as in the qualitative data, it was seen that the defined usability and collective measures can be used for evaluating computer supported collaborative systems. This thesis may also serve as an eye-opener for future collective measures. Some significant results were found in the ANOVA tests and linear regression which gives strength to our results. In fact, the qualitative analysis supported the quantitative analysis by offering more insight into the collective *Task process* and the related user behaviour.

The influence of condition did not reach a significant level which indicated that either i) more observations could be needed to reach significance or ii) equipped with the given task the conditions were too similar. That is, the condition did not significantly influence the way the participants solved the specific task given to them. However, difference in Task did significantly influence the measure *Monitoring*.

The qualitative study showed that the action-over-time-graphs can be used to evaluate the systems and to derive insights to collective behaviour and the *Task process* of the participants. For instance the clusters in the action-over-time-graphs does say something about task-solving, the whiteboard and conversations. The outcome of the qualitative analysis is presented in table 48.

Table 50: Characteristics of the conditions and tasks

Condition	Users' characteristic behaviour
Co-located	Task-solving and conversational clusters
Skype Video	Whiteboard interaction, specific clustering and frequently talking
CollaBoard	Looking at task description, conversational clusters and Laughing
Task	
Easy	Looking at task description and whiteboard and Laughing
Average	Task-solving and erasing
Hard	Laughing, specific clustering and erasing

Table 50 shows a summary of the results seen in chapter 4.3. User's characteristics behaviour is stated for the conditions and tasks. The user's characteristics for Co-located condition is task-solving and for Skype Video focus on the whiteboard. For the CollaBoard condition most focus is given to *Looking at the task description* and *Laughing*. That is, there is a difference in focus seen in the conditions, however, this did not induce significant differences in means of the quantitative measures. This means that the qualitative analysis can show interesting aspects of the *Task process* not seen in the quantitative analysis.

In the analysis of tasks, some additional users' characteristic behaviour were found. A characteristics of the easy task was *Looking at task description* and looking at the whiteboard while for the average task the task-solving is more in focus. For the hard task the most focus is on structured behaviour and *Erasing*. Structured behaviour was defined as a specific pattern of action-blocks over time. the Also more *Erasing* is done in the average task. Most *Laughing* was done in the hard and easy tasks.

6.2 Implications

The most common collaborate systems used today, by average computer users at home, is Skype Video or something equal to that. A problem in this technology is that when people are working on a shared application it is impossible to follow what happens and where it happened. Also the communication connected to this has a lot of talking where words like “where, this and here” are used a lot which makes the collaboration slow and causes irritation from both practitioners. The technology is however moving forward and systems involving overlays and 3D will most likely be delivered as a standard with an average computer user's PC. The reason for evaluating these kinds of systems is that the support for behaviour is not always considered in the product development. The main goal for that system is to make the system support behaviour so that it acts as natural as if the participants were actually in the same room.

This study can contribute to CSCW research in filling the gap and the need for usability and collective measures in evaluation. These measures could be used to evaluate computer supported collaborative systems in order to better understand the *Task process* and the collective behaviour in a collaborative environment.

In this study, however, the results can not be generalized to all tasks or collective behaviour since it was done with a specific task and conditions. Also, dot-to-dot puzzles are not likely to be part of everyday use for a collaborate system. However, with some care, the results can be generalized to other kinds of problem-solving and to understand how users collaborate in such settings. We have learned that usability and collective measures can be used both in a quantitative and a qualitative analysis. This means that usability and collective measures like the ones used here can and should be used by researchers in future studies. This is important since it can help to solve the problems with usability connected to many systems today.

Today CSCW systems are not used by everyone, but since interactive technology is growing this may change in a near future. Also there is a need for the systems to solve harder tasks in for instance engineering or construction. There are other suitable areas for video conference systems with new technology like CollaBoard in teaching, business meetings, introducing new products, for training etcetera which can help to save time, environment and money.

6.3 Future studies

In evaluating a system there needs to be more work on the how the users think. Understanding how users interact with each other in a computer-mediated setting is of importance. In the study presented, usability and collective measures were explored. Still, more detailed research is needed. Three main areas of future research are shown next:

First, the descriptive measures should be investigated further. This will be done in order to see if statistical significant difference can be seen for Condition or Task. Also there is a need to investigate other collective measures. Second, since the condition in the ANOVA did not reach significance more research is needed. More observations could result in a significance but also another task or additional conditions could be tested. Third, in order to fully fill the gap seen in the literature study more research in diversity, organisations and long term studies is needed. It is important to study what kind of task it is, what kind of participants there are in the study regarding what kind of strategies they choose for solving a problem and what kind of relations they have in order to draw conclusions about what is really happening in a collaborate session.

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Data from literature study **Appendix II**

All data presented in Chapter 2 are summarised in Table 1. In authors, all surnames of the authors are stated in order to see what authors that co-operate their initials is not included due to space and is seen in the reference list or in Appendix I were the titles of the papers also are found. The papers are ordered by year of publication ranging from 1988 to 2010. Frame of paper and study in paper are stated.

Table 1: Full data from literature study, 41 papers reviewed

		Frame of paper			**Study in paper**		
Author/-s	**Year of publication**	**Method in paper**	**Kind of collaboration**	**Measures studied**	**Method in studies**	**Number of participants**	**Conclusions**
Bly	1988	User study	Remote and co-located	Interaction, performance, feedback and sketching	Observation, video recording and experiment (self observation)	2	
Grudin	1988	Theoretical with case studies	Neither	Natural behaviour, performance and presence disparity		4	
Bullen and Bennett	1990	User study	Remote	Social organization, usability and design	Observation and interview	223	
Tang and Minneman	1991	User study	Remote	Gestures, natural behaviour, conversation, embodiment and sketching	Observation	28	Awareness supports collaboration
Dourish and Bly	1992	User study	Remote	Awareness	Questionnaire	15	
Kaplan, Tolone, Bogia and Bignoli	1992		Remote	Awareness, coordination and task process	No formal study, used No formal study, used daily development and maintenance, observation		
Orlikowsky	1992	User study	Remote	Interaction, social organization, work coupling, perception/cognitive aspects and culture	Observation, interview, notes/documents, long-term, daily	91	
Gaver, Sellen, Heath and Luff,	1993	User study	Remote	Task process and casual interaction	Observation	12	
Peng	1993	Theoretical with case studies	Remote	Ownership, tool, information given and sketching	Case studies	9	
Neuwirth, Kaufer, Chandhouk and Morris	1994	Theoretical	Remote	Interaction, coordination, roles and need			
Prakash and Shim	1994	Theoretical	Remote	Natural behaviour, satisfaction and individual versus shared workspace			
Saeki	1995	Theoretical	Co-located	Conversation, task process and author styles			
McCarthy and Anagnost	1998	User study	Neither	Awareness, performance, satisfaction, perception/cognitive aspects and environment	Observation and logs	71	
Ocker and Yaverbaum	1999	User study	Remote and co-located	Conversation, performance, roles, satisfaction and learning	Experiment	43	
Gutwin and Greenberg	2000	Descriptive	Co-located	Conversation, performance, coordination, satisfaction, work coupling, privacy and monitoring			

Baker, Greenberg and Gutwin	2001	Theoretical	Remote	Interface, shared artifact, privacy, feedback, embodiment, coordination, conversation and gestures			
Gutwin and Greenberg	2002	Descriptive	Remote	Awareness, gestures, conversation, embodiment, feedback and shared artifact	Unstructured observation		
Fussell, Setlock, Parker and Yang	2003	User study	Remote	Performance	Questionnaires pre-, experimental and post, and video recording	38	
Scott, Grant and Mandryk	2003	Theoretical	Co-located	Transition between activities, physical object/product, individual versus shared workspace, embodiment, interaction, conversation and natural behaviour			
Neale, Carroll and Rosson	2004	User study	Remote and co-located	Awareness, conversation, coordination, performance, shared artifacts and work coupling	Interview, questionnaires, logs, notes/documents in a long-term study with artifacts	>100	
Sugimoto, Hosoi and Hashizume	2004	User study	Co-located	Awareness and interaction	Lab/experiment measuring performance using logs	22	
Heiser, Tversky and Silverman	2004	User study	Remote and co-located	Gestures, usability, physical object/product, performance and satisfaction	Measuring performance using logs	30	Gestures and a shared sketch supports collaboration
Fussell, Setlock, Parker and Yang	2004	User study	Remote	Gestures, conversation and performance	Lab/experiment and questionnaires	96	
Gutwin, Penner and Schneider	2004	User study	Remote	Awareness and shared artifacts	Unstructured interview and notes/documents	14	Awareness supports collaboration
Tang, Boyle and Greenberg	2004	Theoretical	Mixed presence	Embodiment, presence disparity, social organization, perception/cognitive aspects and technology			
Tang and Greenberg	2005	Theoretical	Mixed presence	Awareness, natural behaviour, conversation, embodiment, satisfaction and presence disparity			
Narayan, Waugh, Zhang, Bafna and Bowman	2005	User study	Remote	Performance, usability and immersion	Lab/experiment	24	
Kirk and Fraser	2005	User study	Remote	Gestures, roles, sketching, ecology and conversation	Experiment	18	Gestures supports collaboration
Kirk, Crabtree and Rodden	2005	User study	Remote	Awareness, gestures, ecology and social organization	Lab experiment	48	
Ju, Neeley, Winograd and Leifer	2006	User study	Co-located	Interaction, task process and sketching	Observation in a lab experiment	24	A shared sketch supports collaboration
Kirk and Fraser	2006	User study	Remote	Gestures, performance, ecology and conversation grounding	Experiments and questionnaires	96	Gestures supports collaboration
Tang and Greenberg	2007	User study	Mixed presence	Gestures, natural behaviour, interaction, embodiment, presence disparity, feedback, feedthrough and group size	Observation	22	Gestures supports collaboration
Epps and Close	2007	User study	Remote	Awareness, roles, presence disparity, eye gaze and natural behaviour	Observation	18	

DiMicco, Hollenbach, Pandolfo and Bender	2007	User study	Mixed presence	Awareness, interaction and coordination	Experiment and questionnaires	100	
Wickey and Alem	2007	User study	Remote	Awareness, gestures, natural behaviour, performance and task process	Observation, interview and video recording	42	
Bezerianos and McEwan	2008	User study	Mixed presence	Awareness, coordination and presence disparity	Controlled lab experiment, questionnaire, logs and video recording	32	
Nam	2008	User study	Remote	Awareness, natural behaviour, gestures and performance	Lab-based experiment, observation, interview and questionnaire	9	
Burkhardt, Détienne, Hébert and Perron	2009	Theoretical	Neither	Coordination, task process, satisfaction, individual versus shared workspace, conversation grounding, motivation and ergonomics			
Tee	2009	User study	Remote	Awareness, conversation, coordination, roles, individual versus shared workspace, feedback, privacy, casual interaction and monitoring	Observation and semi-structured interviews	17	Casual interaction supports collaboration
Vyas	2009	User study	Remote	Awareness, gestures, natural behaviour, embodiment and individual versus shared workspace	Observation, interview, long term study	10	
Cherubini, Oliviera, Oliver and Ferran	2010	Theoretical	Remote	Awareness, gestures, natural behaviour, interaction, embodiment, roles and eye gaze			

Order of watching videos **Appendix III**

The order of how the videos was watched is seen in Table 1.

Table 2: Order of the videos

Room number	Condition
1	CollaBoard
1	Co-located
2	Co-located
1	Skype Video
2	CollaBoard
2	Skype Video

The Table (Table 1) shows the order of watching the videos. The same order was seen in the nine studies.

Speaking

Calculations for Speaking for single linear regression and multiple linear regression.

Table 3: Model summary

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,585[a]	,342	,315	29,50165

a. Predictors: (Constant), Task

b. Dependent Variable: Speaking

Table 4: ANOVA values

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11300,056	1	11300,056	12,983	,001[a]
	Residual	21758,685	25	870,347		
	Total	33058,741	26			

a. Predictors: (Constant), Task

b. Dependent Variable: Speaking

Table 5: Coefficients for Linear Regression for Task

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	12,407	15,022		,826	,417
	Task	25,056	6,954	,585	3,603	,001

a. Dependent Variable: Speaking

Table 6: Model summary for Linear Regression for Task and Task time

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,876[a]	,767	,748	17,90339

a. Predictors: (Constant), Time, Task

b. Dependent Variable: Speaking

Table 7: ANOVA values

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	25365,986	2	12682,993	39,569	,000[a]
	Residual	7692,754	24	320,531		
	Total	33058,741	26			

a. Predictors: (Constant), Time, Task

b. Dependent Variable: Speaking

Table 8: Coefficients for Linear Regression for Task and Task time

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7,981	9,140		,873	,391
	Task	-1,354	5,805	-,032	-,233	,818
	Time	,054	,008	,897	6,624	,000

a. Dependent Variable: Speaking

Monitoring

Data for the multiple linear regression and ANOVAs. First the two-way and then the one-way. Figure 1 shows the result from the one-way ANOVA.

Table 9: Model summary

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,973[a]	,946	,941	111,14179

a. Predictors: (Constant), Time, Task

Table 10: ANOVA values

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5185923,061	2	2592961,531	209,914	,000[a]
	Residual	296459,960	24	12352,498		
	Total	5482383,021	26			

a. Predictors: (Constant), Time, Task

b. Dependent Variable: Monitoring

Table 11: Coefficients for Linear Regression for Task and Task time

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	56,846	56,742		1,002	,326
	Task	-100,271	36,038	-,182	-2,782	,010
	Time	,837	,050	1,088	16,667	,000

a. Dependent Variable: Monitoring

Data for the two-way ANOVA

Table 12: Between-Subjects Factors

Between-Subjects Factors

		Value Label	N
Condition	1,00	Co-located	9
	2,00	Skype Video	9
	3,00	CollaBoard	9
Task	1,00	A	9
	2,00	B	9
	3,00	C	9

Table 13: Descriptive Statistics

Descriptive Statistics

Dependent Variable:Monitoring

Condition	Task	Mean	Std. Deviation	N
Co-located	A	484,8833	302,96416	3
	B	770,2733	474,88385	3
	C	753,6400	254,99142	3
	Total	669,5989	338,85827	9
Skype Video	A	740,1533	649,36814	3
	B	350,3167	107,19438	3
	C	1212,7200	186,00236	3
	Total	767,7300	506,77465	9
CollaBoard	A	260,9067	130,12871	3

	B	788,0067	453,36506	3
	C	1392,8900	143,83326	3
	Total	813,9344	549,02496	9
Total	A	495,3144	419,19643	9
	B	636,1989	395,81261	9
	C	1119,7500	334,00361	9
	Total	750,4211	459,19591	27

Table 14: Levene's test

Levene's Test of Equality of Error Variances[a]

Dependent Variable:Monitoring

F	df1	df2	Sig.
2,382	8	18	,060

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Condition + Task + Condition * Task

Table 15: Test of between-subjects effects

Tests of Between-Subjects Effects

Dependent Variable:Monitoring

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3,296E6	8	411985,267	3,392	,015	,601
Intercept	1,520E7	1	1,520E7	125,169	,000	,874
Condition	97791,955	2	48895,977	,403	,674	,043
Task	1930769,600	2	965384,800	7,947	,003	,469
Condition * Task	1267320,580	4	316830,145	2,608	,070	,367
Error	2186500,886	18	121472,271			
Total	2,069E7	27				
Corrected Total	5482383,021	26				

a. R Squared = ,601 (Adjusted R Squared = ,424)

Table 16: Estimated marginal means

Grand Mean

Dependent Variable:Monitoring

Mean	Std. Error	95% Confidence Interval

		Lower Bound	Upper Bound
750,421	67,074	609,503	891,339

Table 17: Post-hoc tests for Condition

Multiple Comparisons

Monitoring

Tukey HSD

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Co-located	Skype Video	-98,1311	164,29802	,823	-517,4465	321,1842
	CollaBoard	-144,3356	164,29802	,660	-563,6509	274,9798
Skype Video	Co-located	98,1311	164,29802	,823	-321,1842	517,4465
	CollaBoard	-46,2044	164,29802	,957	-465,5198	373,1109
CollaBoard	Co-located	144,3356	164,29802	,660	-274,9798	563,6509
	Skype Video	46,2044	164,29802	,957	-373,1109	465,5198

Based on observed means.

The error term is Mean Square(Error) = 121472,271.

Table 18: Post-hoc tests for Task

Multiple Comparisons

Monitoring

Tukey HSD

(I) Task	(J) Task	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A	B	-140,8844	164,29802	,673	-560,1998	278,4309
	C	-624,4356*	164,29802	,004	-1043,7509	-205,1202
B	A	140,8844	164,29802	,673	-278,4309	560,1998
	C	-483,5511*	164,29802	,023	-902,8665	-64,2358
C	A	624,4356*	164,29802	,004	205,1202	1043,7509
	B	483,5511*	164,29802	,023	64,2358	902,8665

Based on observed means.

The error term is Mean Square(Error) = 121472,271.

*. The mean difference is significant at the ,05 level.

Data for the one-way ANOVA

Table 19: Descriptives for the one-way ANOVA for Monitoring and Task

Descriptives

Monitoring

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum
					Lower Bound	Upper Bound	
A	9	495,3144	419,19643	139,73214	173,0915	817,5373	137,50
B	9	636,1989	395,81261	131,93754	331,9504	940,4474	245,05
C	9	1119,7500	334,00361	111,33454	863,0121	1376,4879	497,61
Total	27	750,4211	459,19591	88,37229	568,7693	932,0730	137,50

Table 20: Test om homogenity for Task

Test of Homogeneity of Variances

Monitoring

Levene Statistic	df1	df2	Sig.
,178	2	24	,838

Table 21: ANOVA values

ANOVA

Monitoring

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1930769,600	2	965384,800	6,524	,005
Within Groups	3551613,421	24	147983,893		
Total	5482383,021	26			

Table 22: Robust test

Robust Tests of Equality of Means

Monitoring

	Statistic[a]	df1	df2	Sig.
Welch	6,977	2	15,840	,007
Brown-Forsythe	6,524	2	23,232	,006

a. Asymptotically F distributed.

Table 23: Post-hoc test for Task

Multiple Comparisons

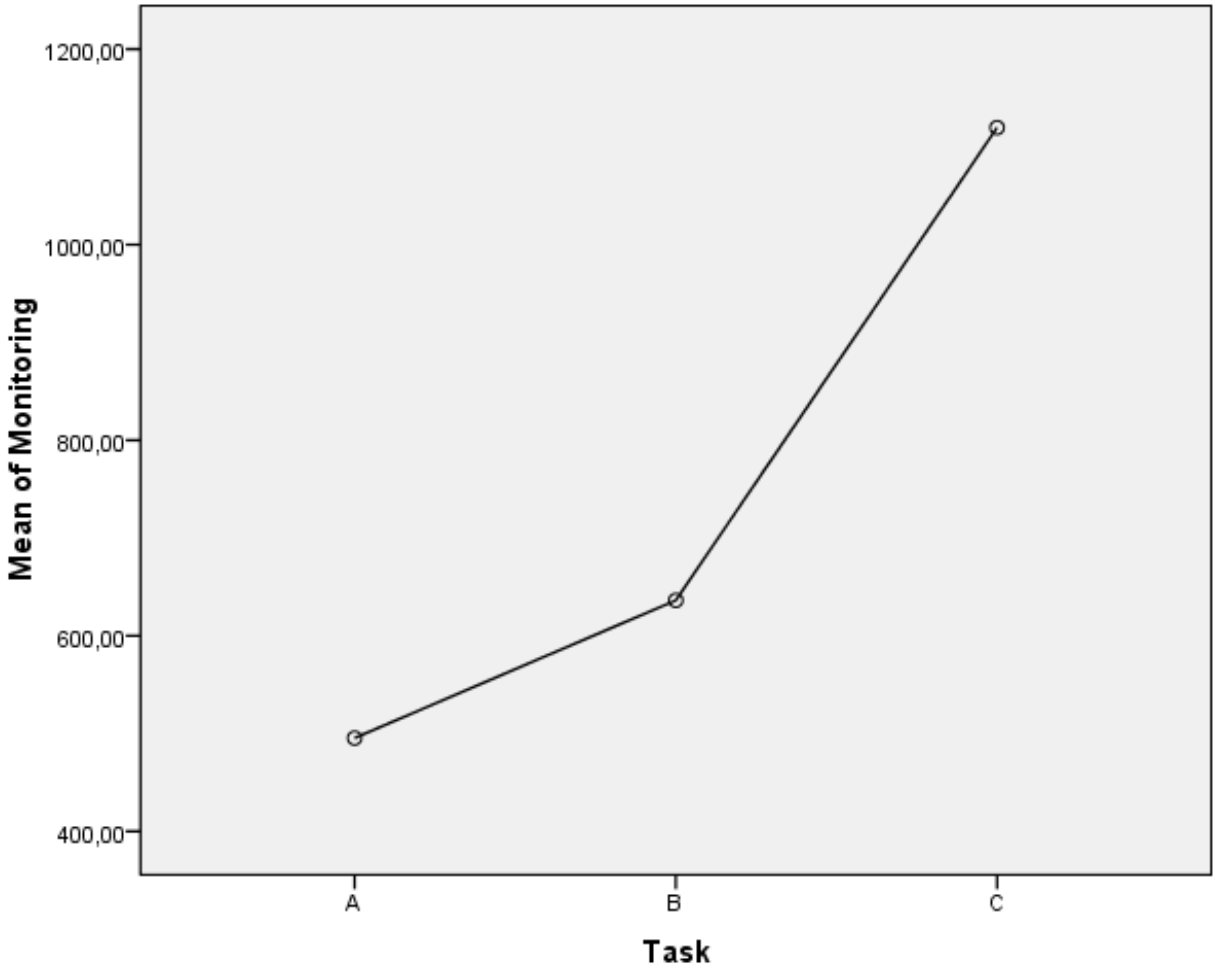
Monitoring

Tukey HSD

(I) Task	(J) Task	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A	B	-140,88444	181,34307	,721	-593,7502	311,9813
	C	-624,43556*	181,34307	,006	-1077,3013	-171,5698
B	A	140,88444	181,34307	,721	-311,9813	593,7502
	C	-483,55111*	181,34307	,035	-936,4168	-30,6854
C	A	624,43556*	181,34307	,006	171,5698	1077,3013
	B	483,55111*	181,34307	,035	30,6854	936,4168

*. The mean difference is significant at the 0.05 level.

Figure 1: Means of Monitoring for Task



Qualitative data: action-over-time-graphs **Appendix V**

The graphs are denoted S for study number followed by the Condition – the Task. Also the Task time is noted and if they did not finish the task. For example S2CO – A means that it is study 2 in room 2, Co-located Condition with Task A. The Conditions are CO for Co-located, SV for Skype Video and CB for CollaBoard. In the Co-located condition there will only be one room, Room 1. Participant 1 is working in Room 1 and Participant 2 in Room 2.

Figure 2: S1CO – A, 0433 min

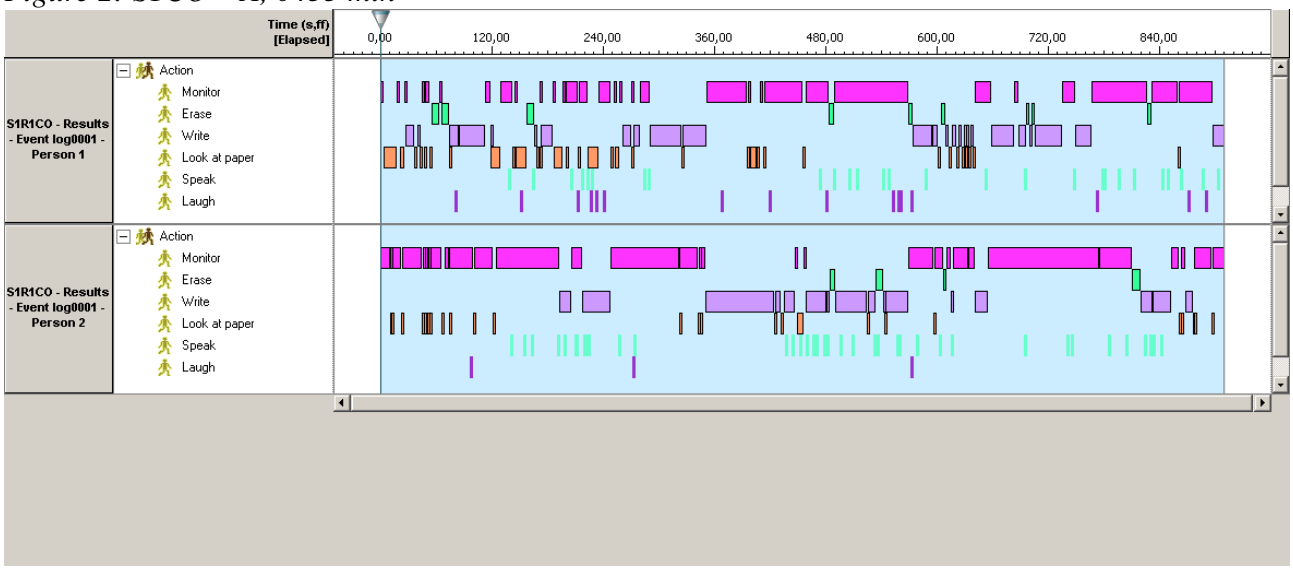


Figure 3: S2CO – C, 0414 min

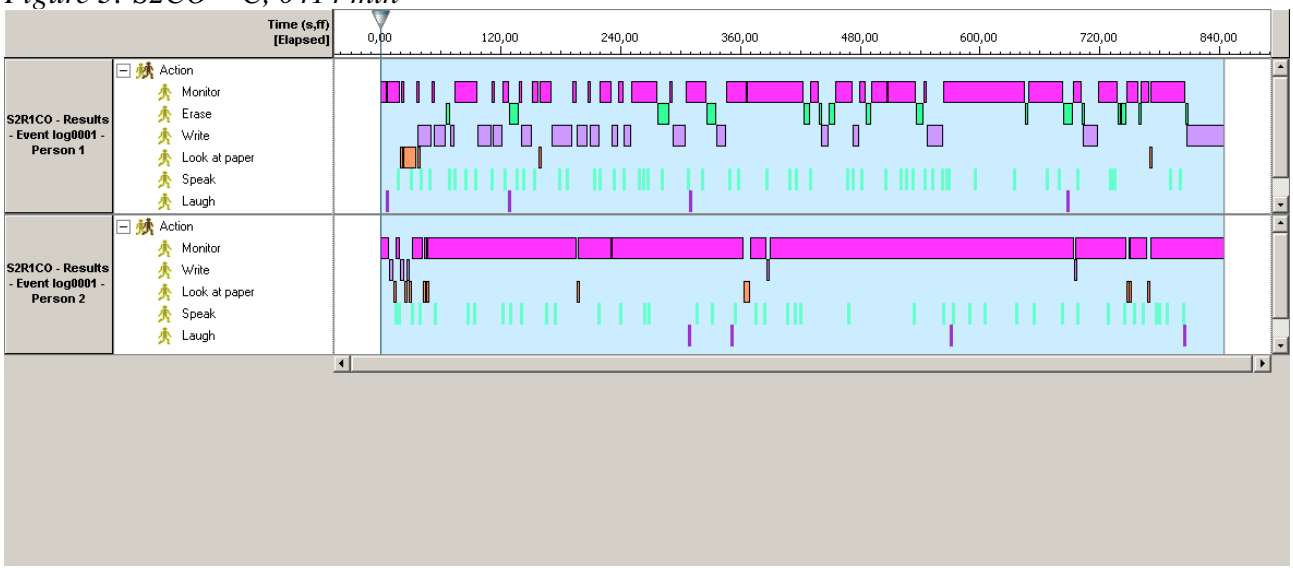


Figure 4: S3CO – D, 0120 min

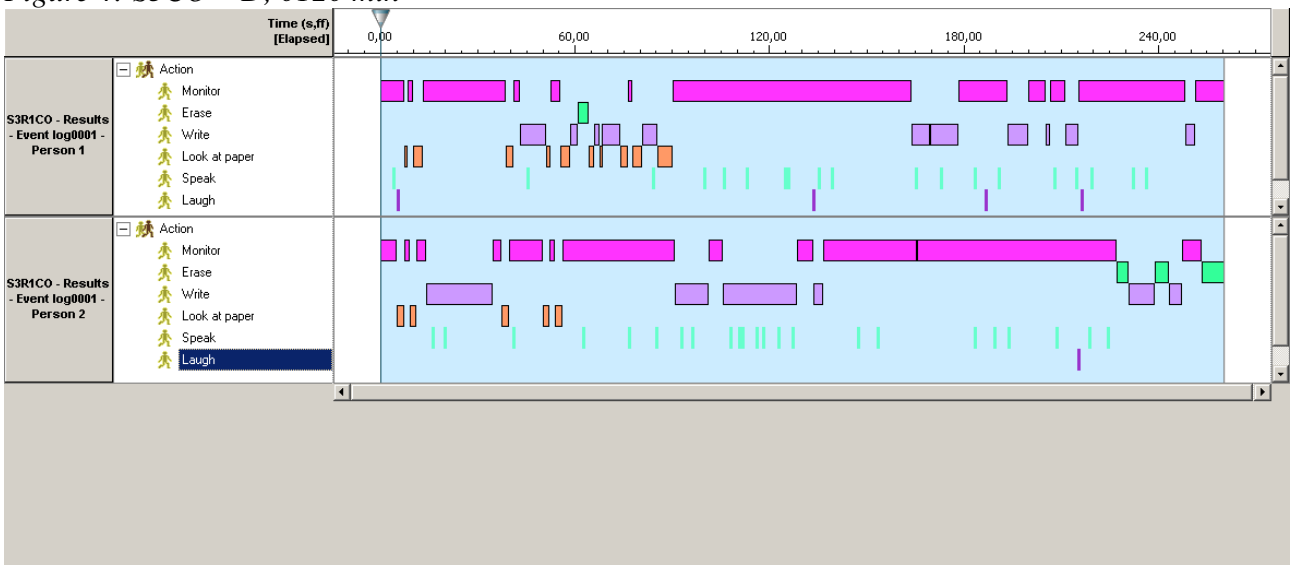


Figure 5: S4CO – D, 0100 min

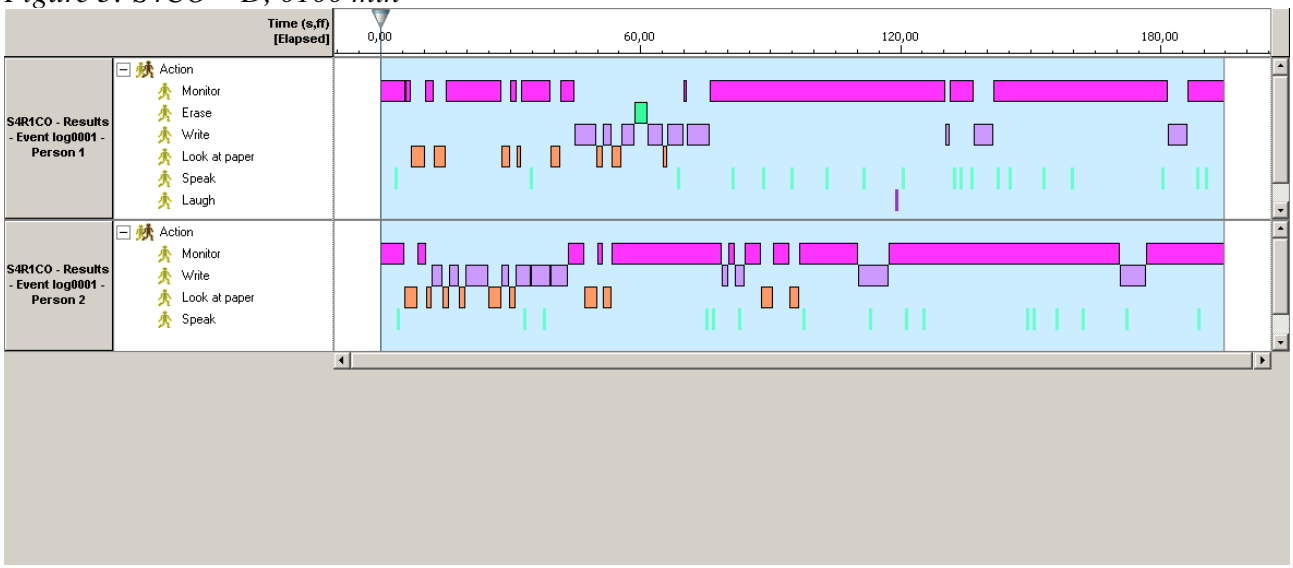


Figure 6: S5CO – A, 0223 min

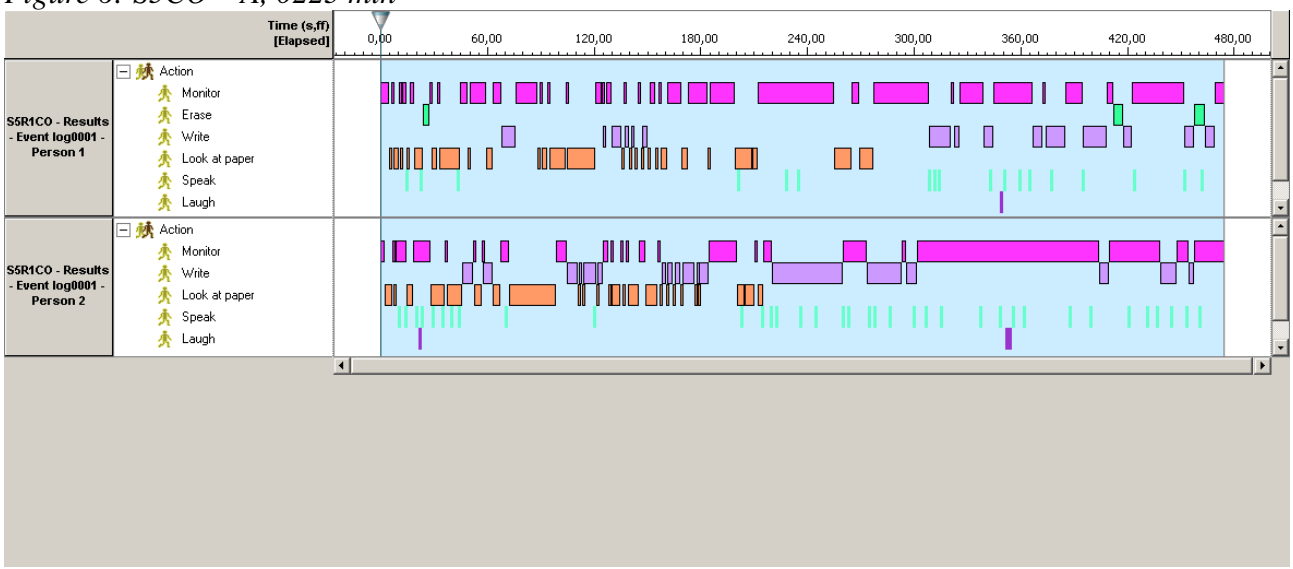


Figure 7: S6CO – C, 0148 min

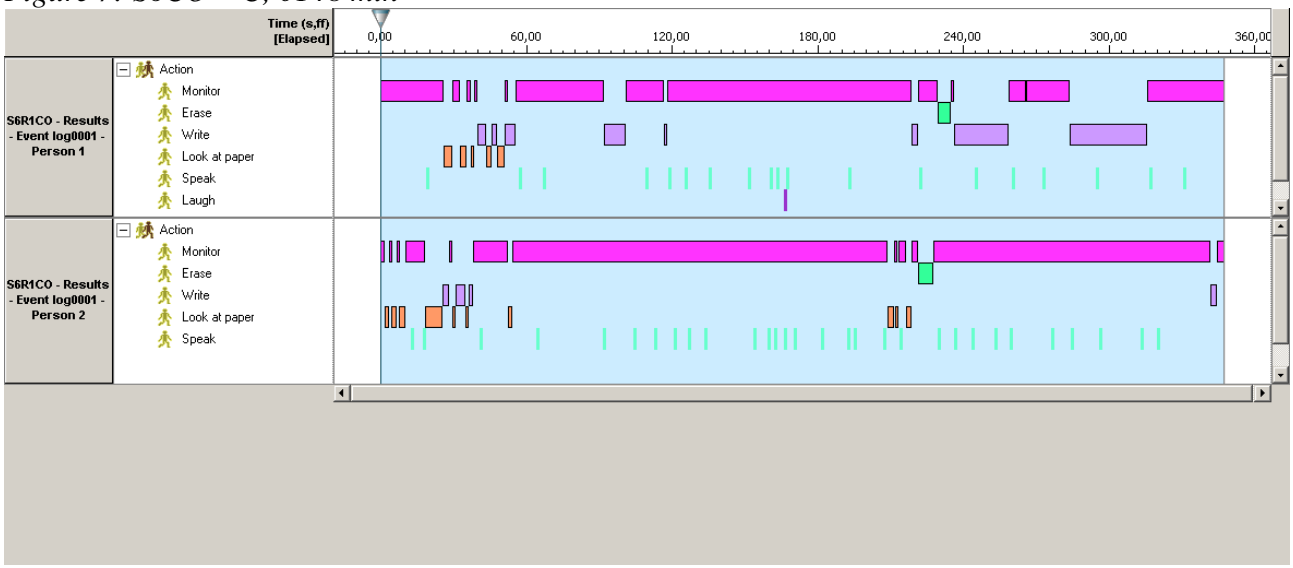


Figure 8: S7CO – A, 0302 min

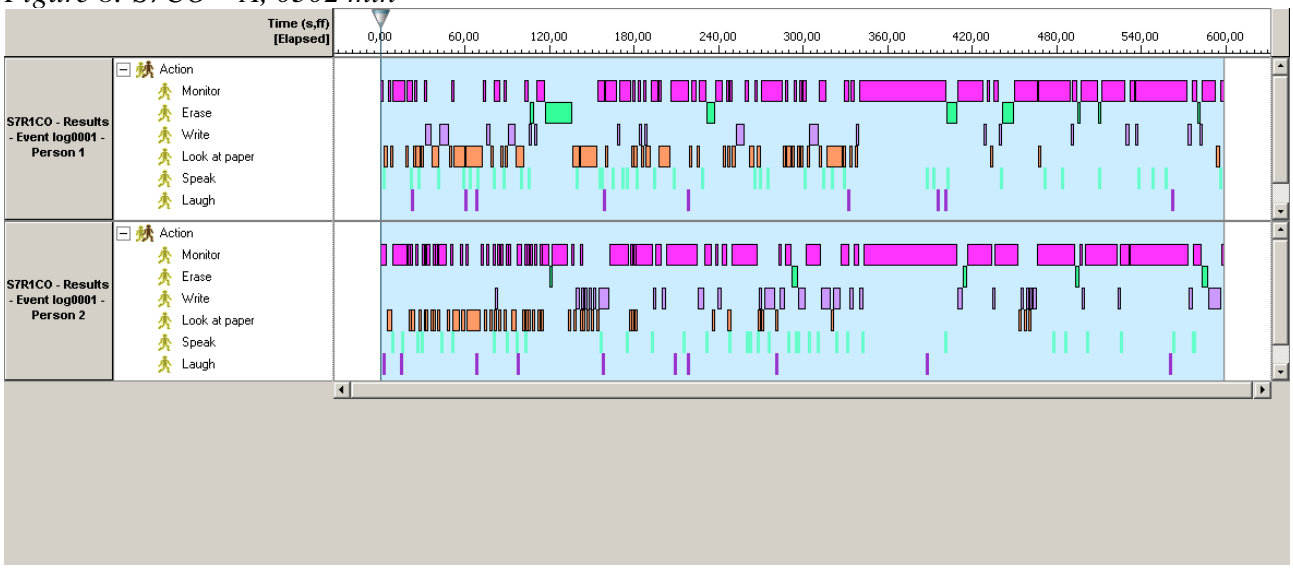


Figure 9: S8CO – D, 0243 min

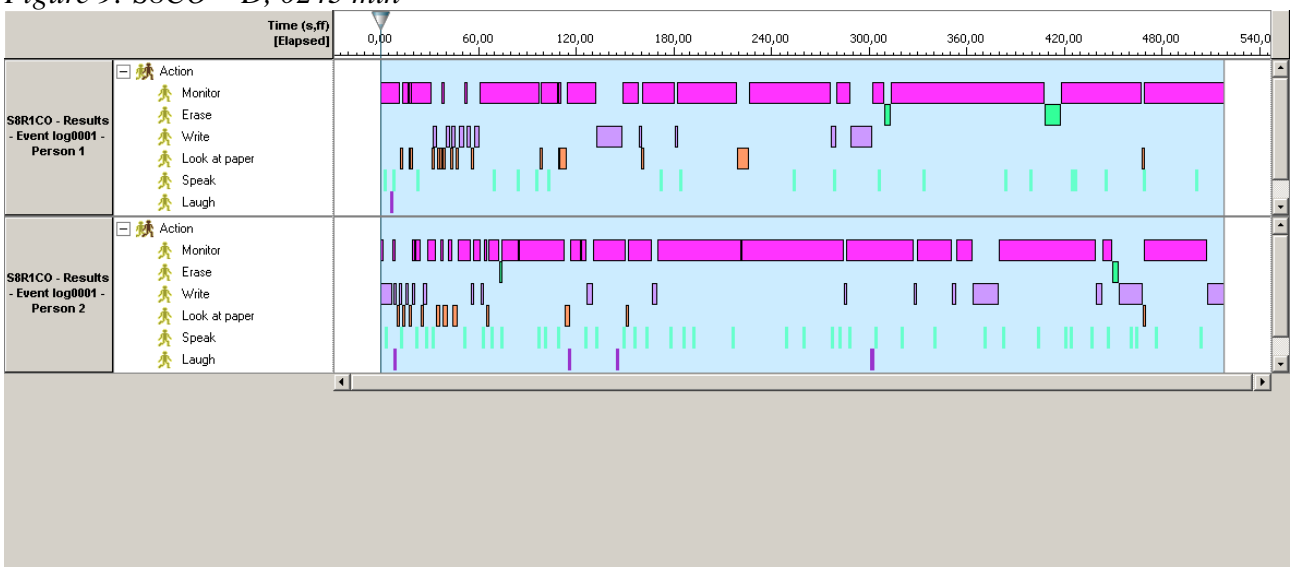


Figure 10: S9CO – C, 0130 min

Figure 11: S1SV – C, 0139 min

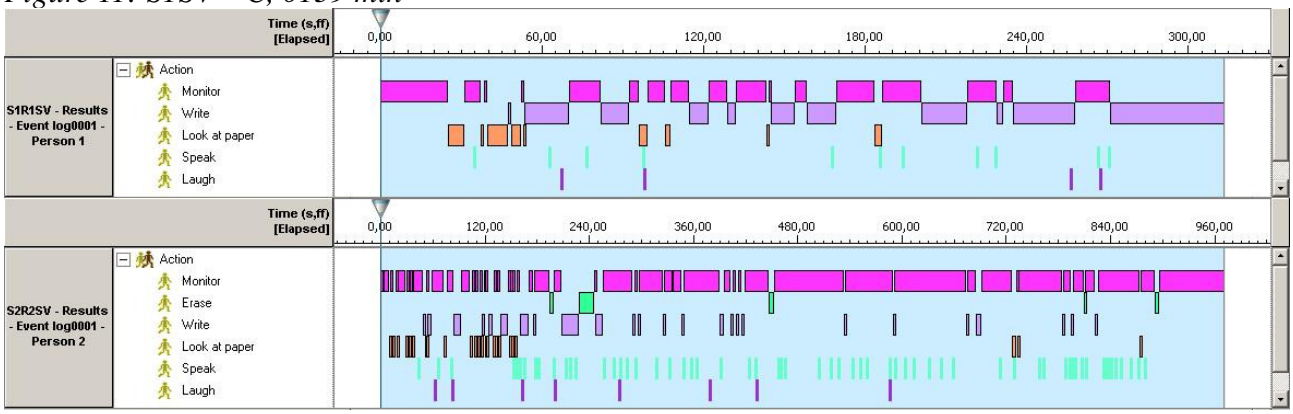


Figure 12: S2SV – A, did not finish

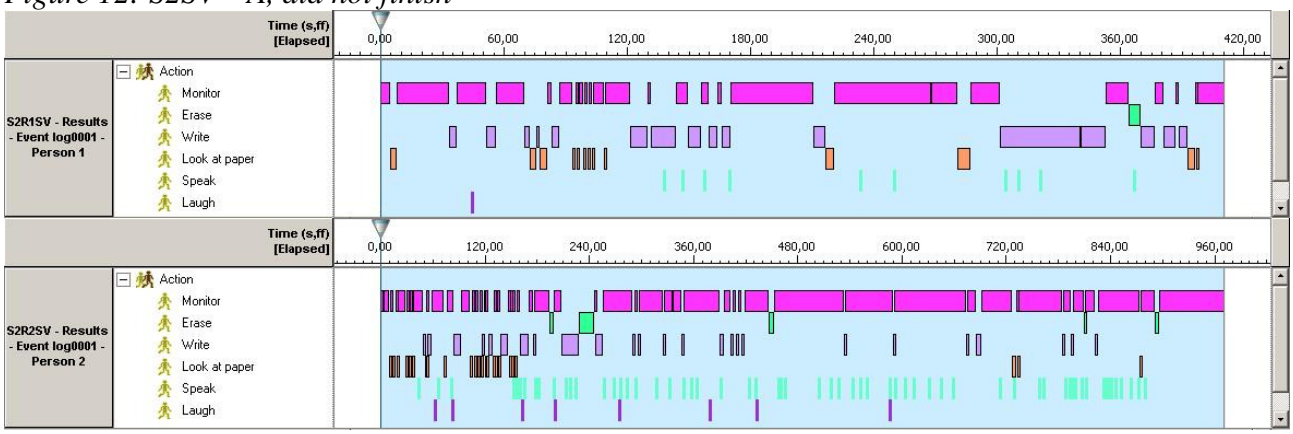


Figure 13: S3SV – A, did not finish

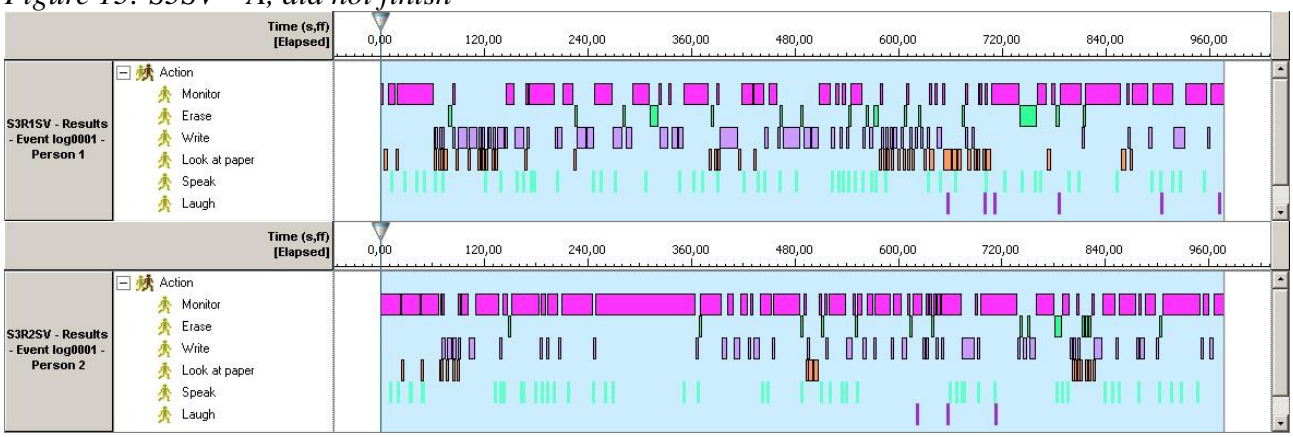


Figure 14: S4SV – C, 0126 min

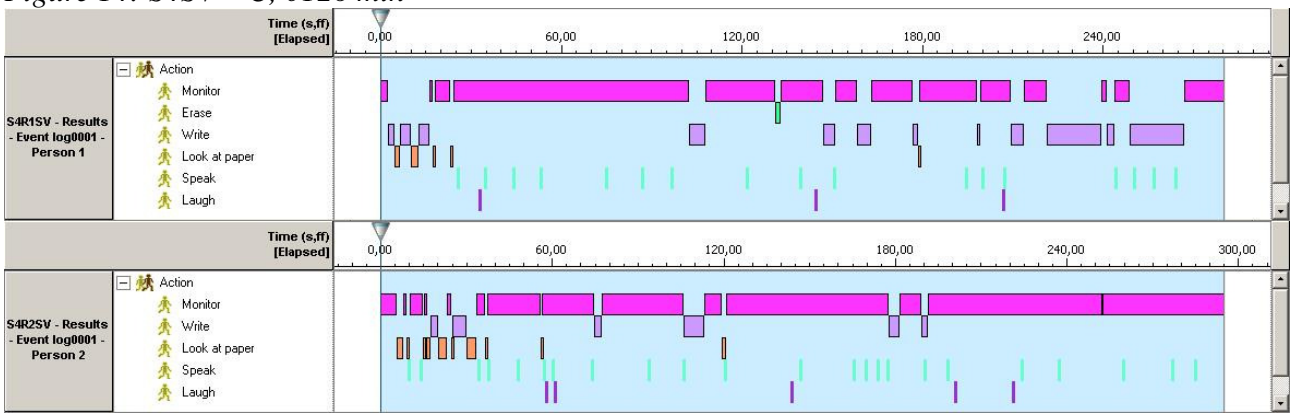


Figure 15: S5SV – D, 0139 min

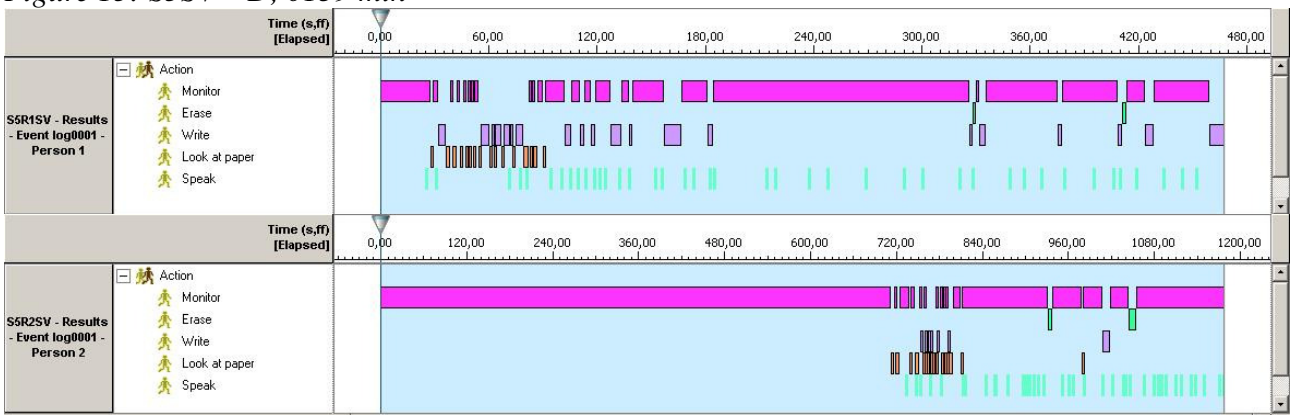


Figure 16: S6SV – D, 0158 min

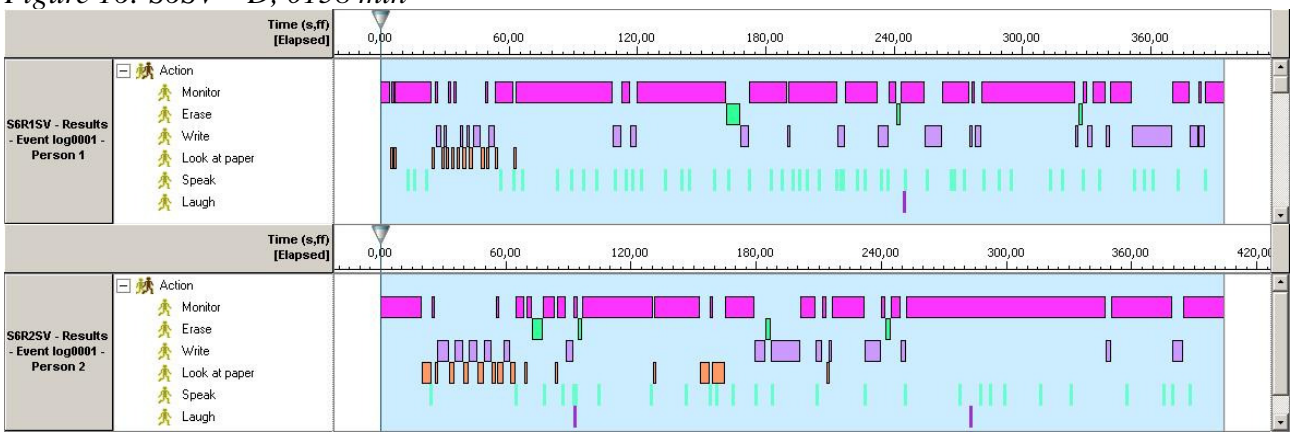


Figure 17: S7SV – C, 0115 min

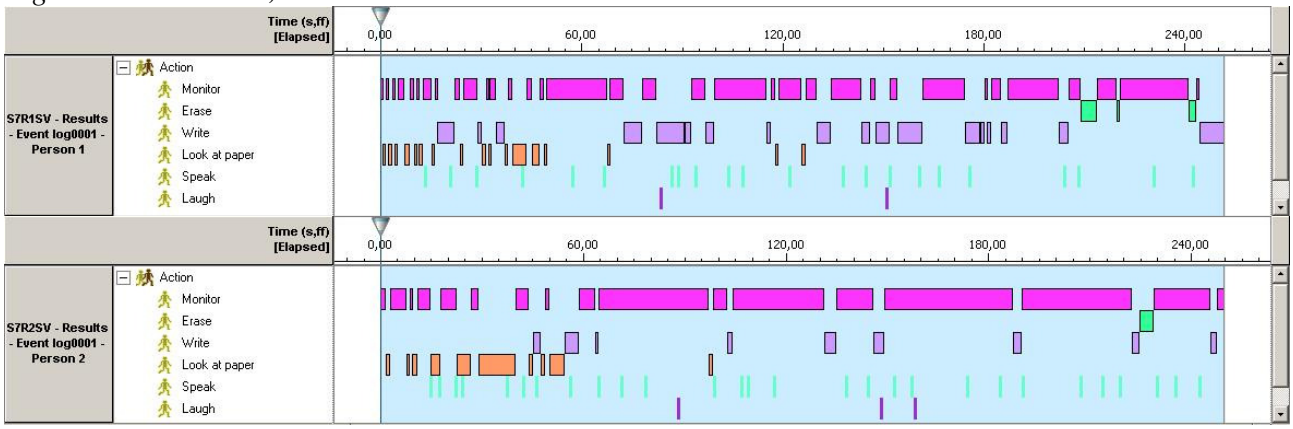


Figure 18: S8SV – A, did not finish

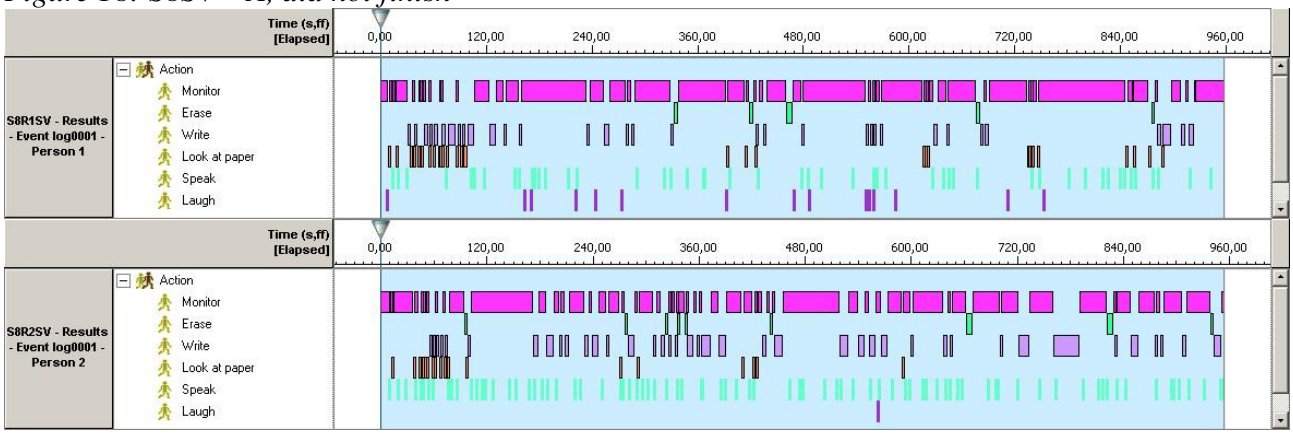


Figure 19: S9SV – D, 0104

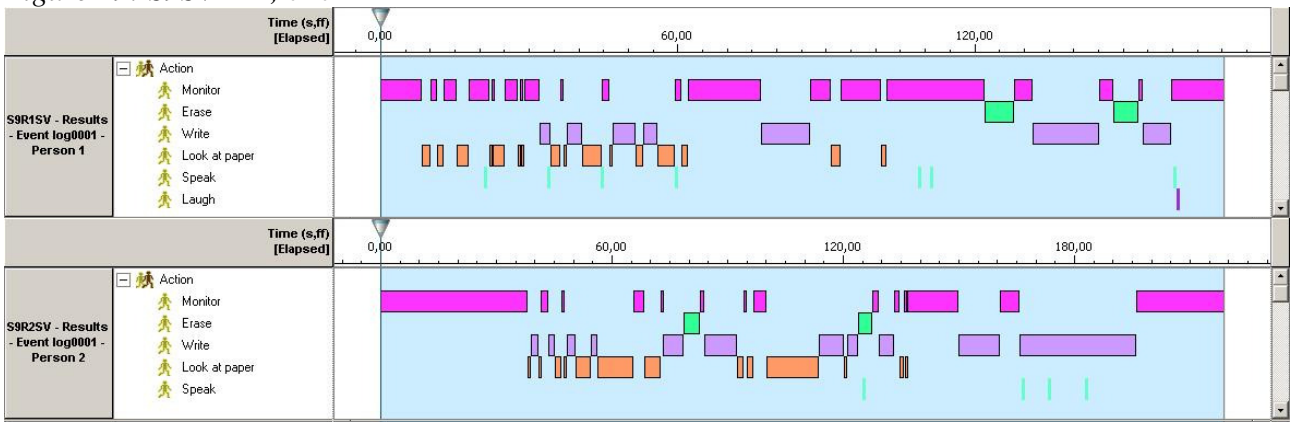


Figure 20: S1CB – D, 0052 min

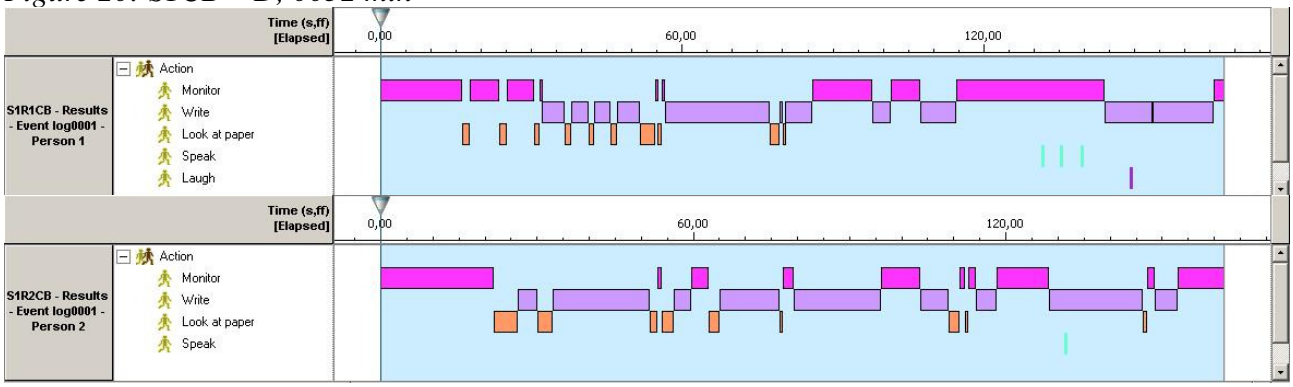


Figure 21: S2CB – D, 0138 min

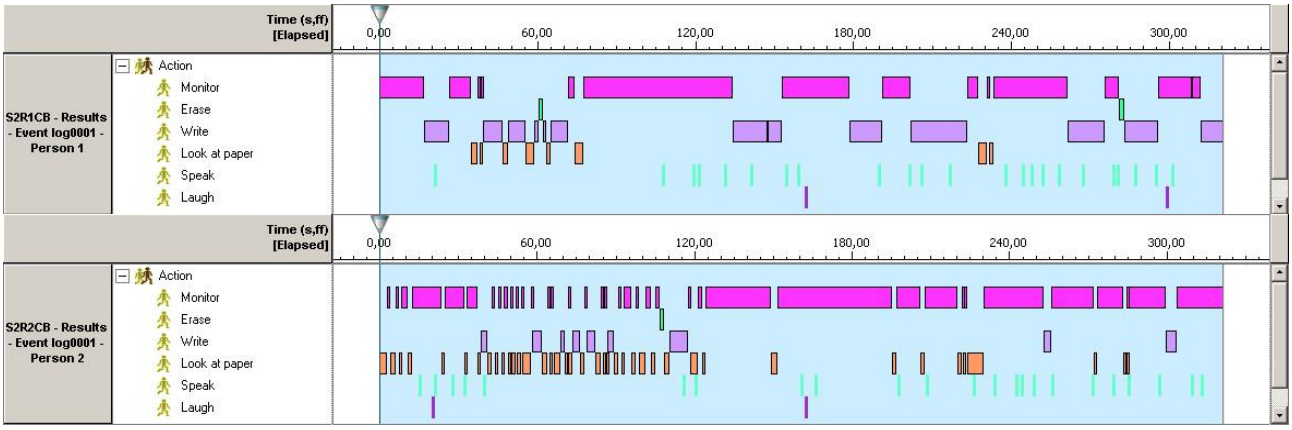


Figure 22: S3CB – C, 0350 min

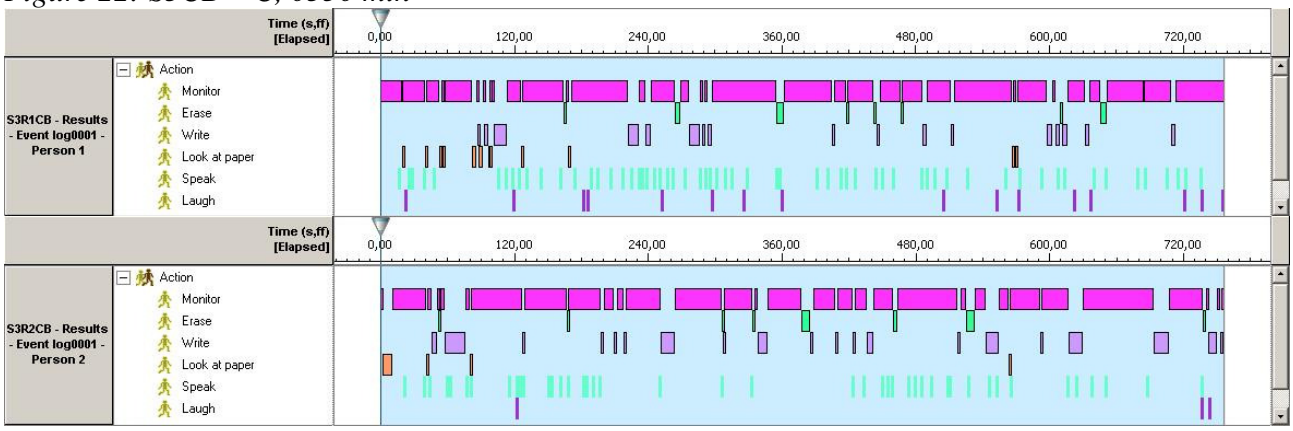


Figure 23: S4CB – A, did not finish

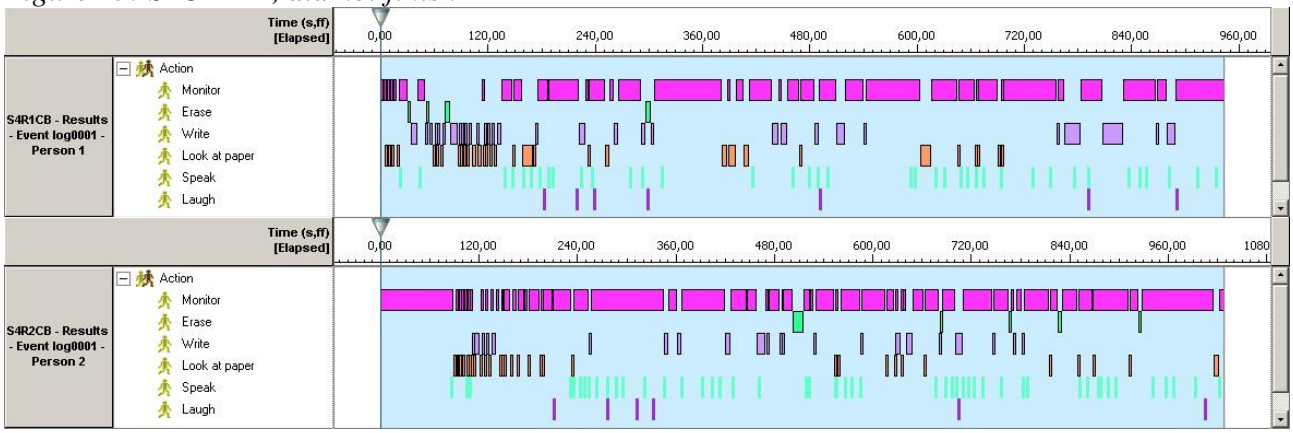


Figure 24: S5CB – C, 0158 min

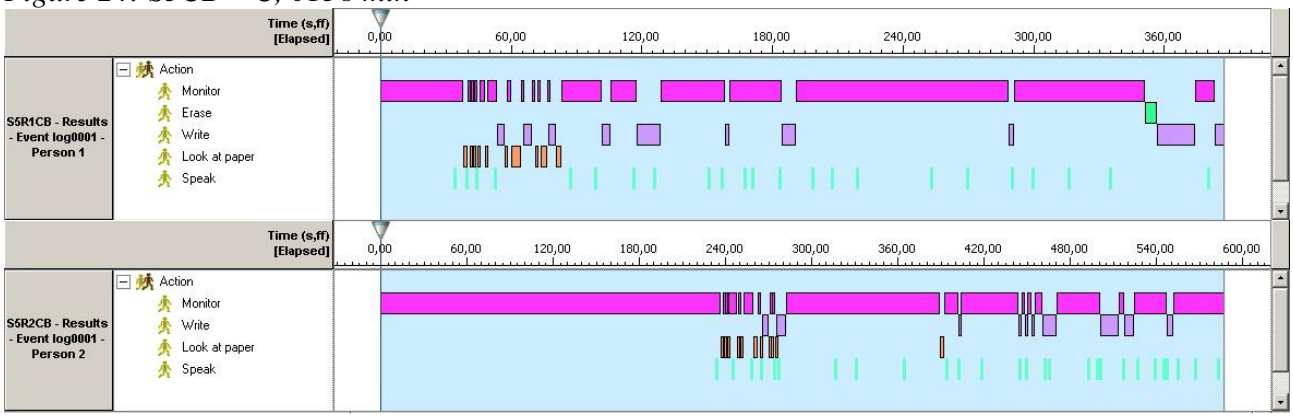


Figure 25: S6CB – A, did not finish

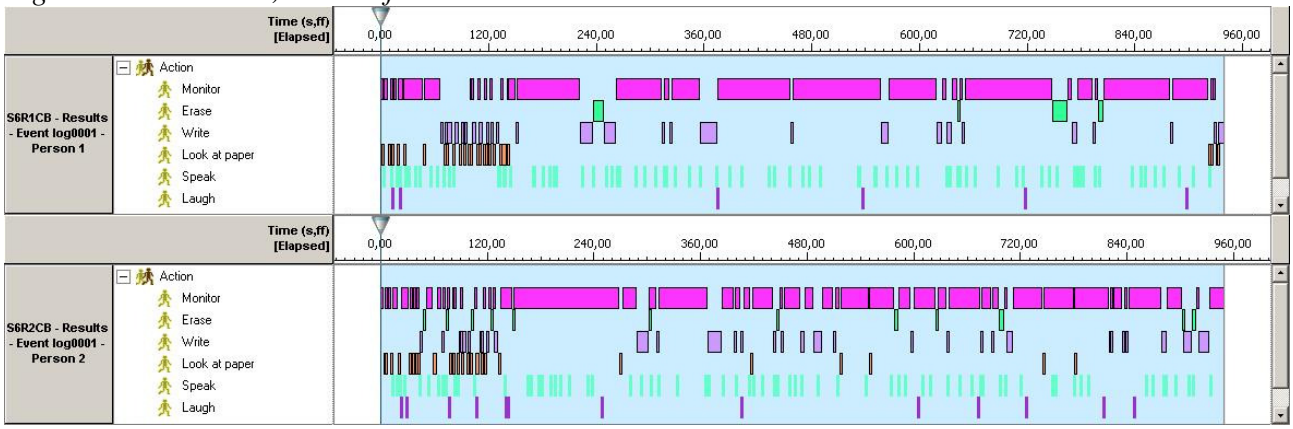


Figure 26: S7CB – D, 0058 min

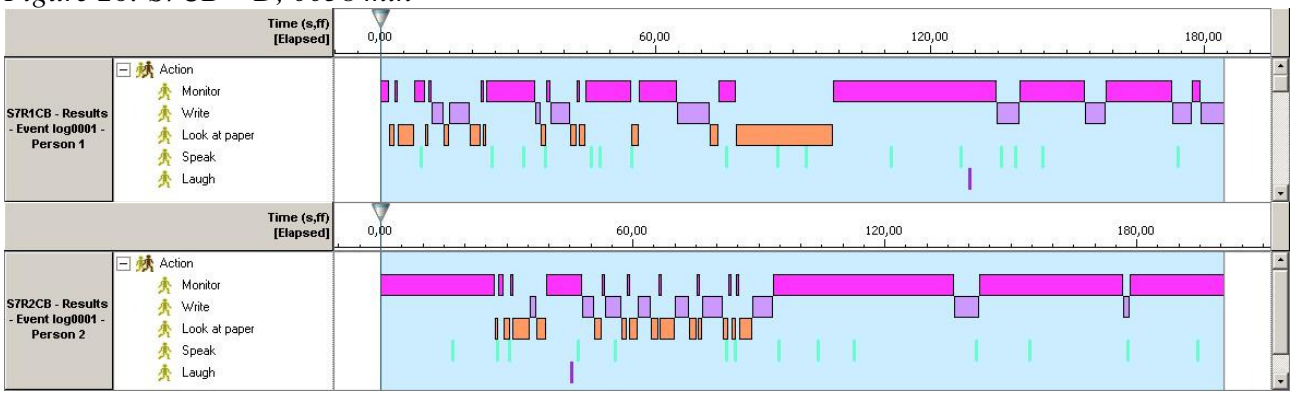


Figure 27: S8CB – C, 0122 min

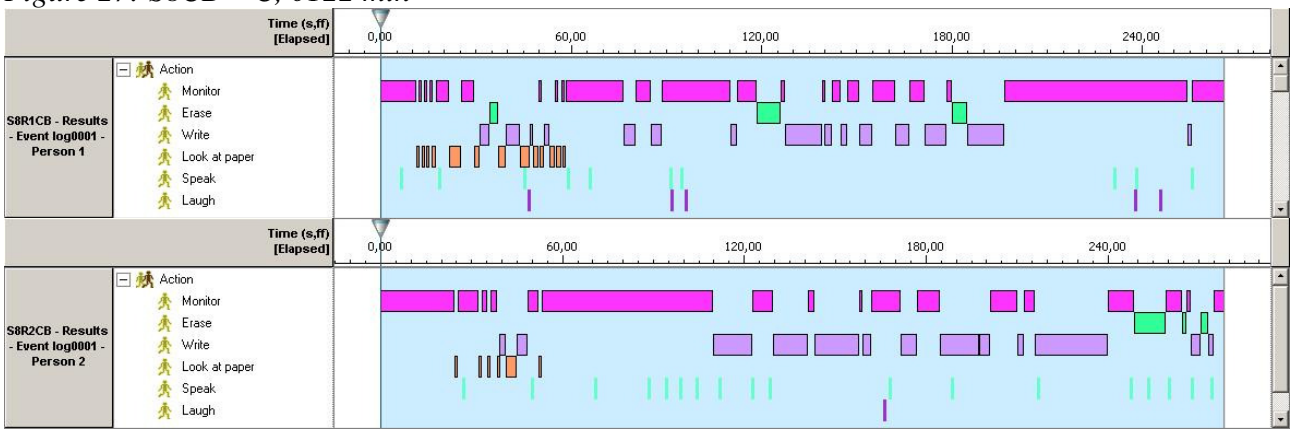
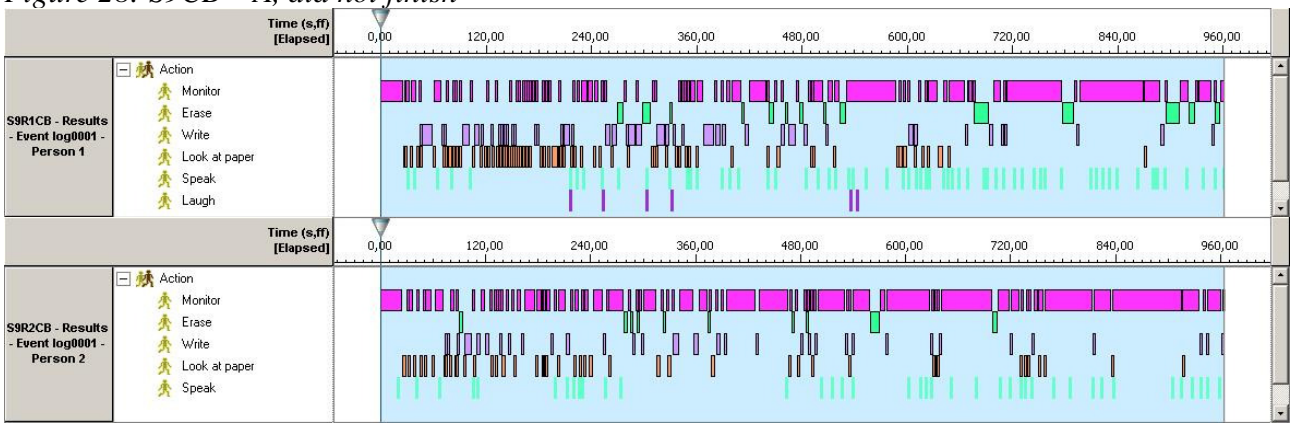


Figure 28: S9CB – A, did not finish



Action-block changes and descriptive data **Appendix VI**

The full table for action-block changes is seen in Table 23. Table 24 shows the additional descriptive information per Group.

Table 23: Full table for action-block changes

Group number Condition, Task Participant	Looking at Task Decription, Monitoring and Writing cluster (LMW)	Speaking and Laughing cluster	Number of times Laughing	Additional descriptive information
Group number 1 Co-located Task A, Participant 1	2	3	16	Alternating LMWs
Co-located Task A,Participant 2	2	3	3	Alternating LMWs
Skype Video Task D, Participan 1	1	0	4	MLW then EM
Skype Video Task D, Participant 2	1	3	8	WML then LM. Monitorer
CollaBoard, Task C, Participant 1	1	0	1	
Participant 2	0	0	0	Writer
2. CO, C, Participant 1	3	0	4	Talker
CO, Task C, Participant 2	1	2	4	Monitorer
SV, Task D, Participant 1	2	1	1	
SV, Task D, Participant 2	1	0	8	Talker. ML then MLW then ML?
CB, Task A, Participant 1	1	2	2	
CB, Task A, Participant 2	1	1	2	LW then MLW then Monitoring
3. CO, D, Participant 1	1	3	4	Alternating LMWs
CO, D, Participant 2	1	1	1	Alternating LMWs
SV, Task C, Participant 1	0	0	6	Many small changes in action-blocks. Talker and writer. Laughing much in the end.
SV, Task C, Participant 2	3	6	3	Many small changes in action-blocks. Monitorer
CB, Task A, Participant 1	2	0	16	Moniterer, talker and laugher
CB, Task A, Participant 2	0	2	3	Moniterer
4. CO, Task D,	1	1	1	Alternating LMWs

Participant 1				
CO, Task D, Participant 2	2	3	0	Alternating LMWs
SV, Task A, Participant 1	1	5	3	MLW then MW until the end
Participant 2	1	0	5	Talker. MLW then MW until the end
CB, Task C, Participant 1	2	3	7	
Participant 2	1	4	6	Talker after MLW. Many small action-blocks for Writing.
5. CO, Task A Participant 1	1	2	1	LW then MLW then MW
Participant 2	3	3	3	Looker in the beginning
SV, Task C, Participant 1	1	0	0	Talker after MLW. MLW then MW
Participant 2	1	0	0	Talker. LMW then M until the end
CB, Task D, Participant 1	1	4	0	
CB, Task D, Participant 2	1	2	0	MLW then MW
6. Co, Task C, Participant 1	1	2	1	
Participant 2	2	0	0	Talker
Skype Video, Task A Participant 1	1	0	1	Talker after MLW. MLW then EMW
Participant 2	1	0	2	Talker after MLW. MLW then EMW then EM
CB, Task D, Participant 1	1	0	6	LM then LMW then MW until the end. Talker
Participant 2	1	0	13	Talker. LM then LMW then small action-blocks of LMW until the end
7. CO, Task A, Participant 1	3	3	9	LW then LMW then LW then MW
Participant 2	2	3	10	LW long time then LMW until the end
SV, Task D, Participant 1	1	0	2	LMW then EM. Talker
Participant 2	1	0	3	LM then LMW then EM. Talker
CB, Task C, Participant 1	3	3	1	
Participant 2	1	0	1	
8. CO, Task D,	2	0	1	Talker

Participant 1				
Participant 2	1	0	4	Monitorer and talker
SV, Task C, Participant 1	4	0	15	Talker. LM then LMW then MW then MLW twice then LM then MLW
Participant 2	3	0	1	Talker. LMW three times then MW
CB, Task A, Participant 1	1	2	5	LM then LMW then EMW until the end
Participant 2	1	3	1	LMW then MW then EM then MW
9. CO, Task C, Participant 1	2	0	1	LMW then MW then LMW then EMW
Participant 2	1	0	1	LMW then EM then M until the end
SV, Task A, Participant 1	2	0	1	LM then LMW twice then EMW
Participant 2	1	1	0	LMW then MW
CB, Task D, Participant 1	3	0	6	Talker after first LMW. Many small action-blocks
Participant 2	1	4	0	Many small action-blocks. LM then LMW many small action-blocks until the end

The Table (Table 23) shows the qualitative analysis in the action-over-time-graphs. Some action-block changes are counted: Looking at Task Description, Monitoring and Writing (LMW) and Speaking and Laughing. Number of times Laughing was also counted. Additional descriptive information includes more action-block changes like: Erasing and Monitoring (EM), Monitoring and Writing (MW) and Looking at Task Description and Monitoring (LM) as well as if there was a trend seen in the graphs. A trend could be is one Participant talked almost all the task time, this is called a Talker. Similar trends could be seen for Monitoring (monitorer), Looking at Task (looker) Description and Writing (writer).

Table 24: Additional descriptive information per Group

Group number	Short time action-blocks in cluster	Participant talks frequently	Participant writes frequently	Participant looks at task description frequently	Participant laughs frequently	Participant monitors frequently	Participants alternate Task solving	Specifik order of clusters
1	0	0	1	0	0	1	2	2
2	0	2	0	0	0	1	0	2
3	2	2	1	0	1	3	2	0
4	1	2	0	0	0	0	2	2
5	0	2	0	1	0	0	0	4
6	1	**5**	0	0	0	0	0	4
7	0	2	0	0	0	0	0	4

8	0	**4**	0	0	0	1	0	4
9	2	1	0	0	0	0	0	5

In Table 24 some numbers are highlighted to show where the highest numbers are. Talkers are seen in Group 6 and 8.