Supporting Distributed Teams with Observability Displays

The effects of Team Experience and Task Complexity

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Abstract

More and more organizations use team-based work settings, as teams can deal with more complex and difficult tasks than a single person can. Due to the technological advances in the last decennia, work is done more often by virtual teams. Coordination within these distributed teams is more difficult as staying aware of each others' endeavors when working distributed is difficult.

Present study focused on the influence of team experience and task complexity on the use of an observability display and coordination. An observability display makes elements (information) visible that are non-observable without explicit effort because of a temporal or spatial boundary. With use of observability information, for example about the task, progression and workload of others, distributed team members can predict what the others will do. Because of this mutual predictability, the coordination process can be more flexible and pro-active.

As the usefulness of an observability display might depend on the degree to which team members are familiar to each other and have developed a shared mental model, present study examined the influence of team experience on the use of an observability display and coordination. Next to that, the influence of task complexity on the use of an observability display and team coordination was examined, as the use of a display to coordinate tasks may depend on the attention that is needed for the tasks the team members are working on.

An experiment in which 16 three-person teams worked on a Sudoku puzzle-task was conducted. During six trials of 20 minutes, distributed team members had to solve Sudoku puzzles and coordinate work by using an observability display. In order to examine the effect of task complexity, half of the trials consisted of Sudoku puzzles that were more complex than the puzzles in the other three trials.

Results show that coordination within distributed teams improves over time and use of the observability display remained constant. The observability display was used more in low complexity tasks compared to high complexity tasks and coordination during low complexity tasks was rated higher than coordination during high complexity tasks.

The results showed that distributed teams can be supported with an observability display as it gives team members the possibility to be aware of each others' activities and coordinate tasks without disturbing each other. Coordination within future and ad hoc teams can be supported with an observability display, mainly in low complexity tasks. Results from this study could be used in the development of observability displays.

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1 Introduction

As the world becomes more and more complex and, subsequently, task complexity increases, tasks can often not be performed by one person anymore: the skills, judgments, and experiences of more than one person are required (Katzenback & Smith, 1993; Salas, Cooke, & Rosen, 2008). More and more organizations choose to use team-based work settings in order to deal with complex and difficult tasks. Teams can offer greater adaptability, creativity and productivity and more complex, innovative, and comprehensive solutions than a single person can offer (Katzenback & Smith, 1993; Salas et al., 2008).

Because of the technological advances in the last decennia, there is an increase in virtual teams, next to the traditional face-to-face teams (Alavi & Tiwana, 2002; Alge, Wiethof, & Klein, 2003; Marks, DeChurch, Mathieu, & Panzer, 2005; Saunders & Ahuja, 2006). A virtual team is a group of people who work interdependently with a shared purpose across space, time, and organization boundaries using technology (Lipnack & Stamps, 2000).

Although these distributed teams can have benefits, like an increased flexibility in the selection of people, virtual teams encounter difficulties as well. Working geographically distributed makes it more difficult to develop effective interpersonal relations, there is a greater risk for communication mishaps and team members often experience a lack of awareness of team members' endeavors (Thompson & Coovert, 2006).

An example of teams that encounter the barriers of working distributed is Urban Search And Rescue (USAR) teams. After a man made or natural disaster, these teams are sent to the location of the disaster to excavate victims trapped in voids. An USAR team is divided in several smaller teams, like for example search- and rescue teams, a support group and a command group, each working in different areas. In order to work successfully and efficiently, the different sub teams have to coordinate their activities. However, the three afore mentioned barriers are experienced by USAR teams as well, as coordination breakdowns occur due to a lack of awareness of other teams' endeavors (De Greef, Oomes, & Neerincx, 2009). As the communication between the distributed USAR teams is all explicit and runs through the staff group, staying aware of each other's endeavors is perceived as time and energy consuming.

Since the 1990s, researchers and designers have been working on tools that help members of distributed teams in staying aware of each other (Dabbish & Kraut, 2008). Dabbish and Kraut (2008) describe research into awareness displays, which gives members information about, for example, the activities of other team members. Awareness displays can show, among other elements, the workload of other team members (Dabbish & Kraut, 2008). This information can be used by team members to time their communication attempts, which makes communication between team members become less disruptive. Other examples of information that can be shown on an awareness display are the presence of others and their current and past activities (Röcker, 2010). Observability is based on awareness displays but distinguishes itself from awareness displays, as it focuses more on the concept of joint activity (collaboration and coordination) while awareness displays start from the concept of individual cognitive processes. Using an observability display increases the mutual predictability of the team members and in this way the coordination between the team members might be supported (De Greef, Brons, Van der Kleij, Brinkman, & Neerincx, 2011). Previous research of De Greef et al. (2011) showed that the presence of an observability display during distributed teamwork resulted in an increased activity awareness and increased backing-up behavior, but that perceived workload of the team members increased as well.

The studies that have been performed in to awareness displays and observability displays focused on different kind of teams. Some studies focused on ad hoc teams, while other studies focused on standing teams (Carroll, Neale, Isenhour, Rosson, & McCrickard, 2003; Convertino, Ganoe, Schafer, Yost, & Carroll, 2005; Fransen, Kirschner, & Erkens, 2011). Although many studies conclude that displays can support teamwork, the relation between team experience and the role of an observability display remains unclear. It is not clear whether awareness displays and observability have added value for more experienced teams, or, are mainly beneficial to ad hoc and future teams, of which the team members are not familiar to each other.

Moreover, it is unclear how task complexity interferes with the use of an observability display. The presence of an observability display gives team members an extra task, looking at and updating the display, which resulted in an increased workload, as shown by De Greef et al. (2011). Therefore, it is interesting to examine the relation between task complexity and the use of an observability display.

Goal of this study was to examine the effects of team experience on the use of an observability display. In this study, we focused on future teams and ad-hoc teams. USAR teams are typical ad hoc teams: when a mission starts, the team members often do not have a shared past and therefore are unfamiliar to each other. Next to that, we examined the effects of task complexity on the use of an observability display in order to determine whether tasks of each complexity level could be supported with an observability display.

The next chapters will give an overview of relevant literature and describe the experiment performed to examine the effects of team experience and task complexity. The results of the experiment will show that team experience has a positive effect on coordination within distributed teams. This effect is found in low complexity tasks, but not in tasks of high complexity. The observability display was used more in low complexity tasks than in high complexity tasks but use of the observability display remained constant over time. Recommendations for future research and the development of observability displays will be given.

2 Background

The following paragraphs provide background information about teams, coordination, observability and task complexity. Hypotheses of present study are discussed in paragraph 2.6.

2.1 Teams

A *team* can be defined as two or more individuals with specified roles interacting adaptively, interdependently, and dynamically toward a common and valued goal (Salas, Sims, & Burke, 2005). Examples of teams are cockpit crews, surgery teams, and military teams.

Many taxonomies of teams have been proposed in the last decennia, for example based on the tasks of a team or the interaction and communication of team members (Salas, Sims, & Burke, 2005). Present study focused on the temporal scope of teams: the extent to which they have a shared past and expect to have a shared future as well (McGrath, as cited in Alge et al., 2003), see Figure 1.

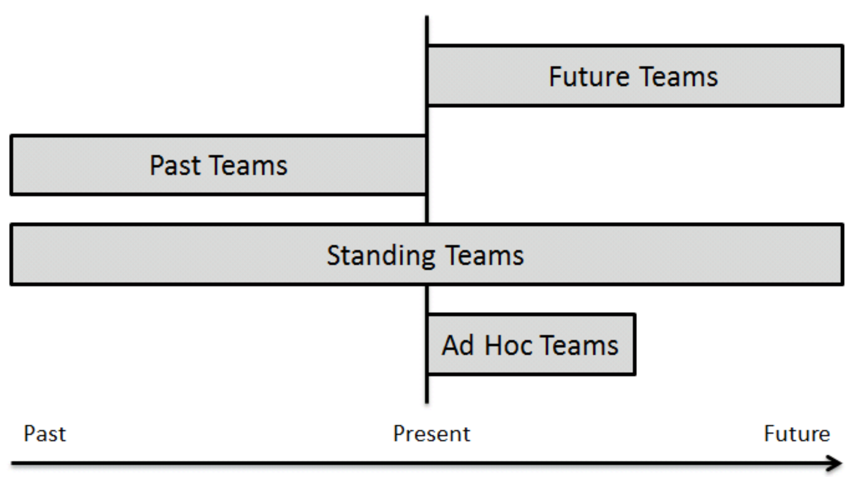

Figure 1: Temporal scope of teams

A *future team* is a team of which the members do not have a shared history but do expect to have interaction in the future. An example of a future team is a project team that has just been started. In a *past team* on the other hand, team members have a shared history, but do not expect to work together as a team in the future (for example, a project team which almost finished the project). *Standing teams* do have shared past experiences and expect to continue team work in the ongoing future (for example, a team that has been working on a project for a long time and which will continue with it in the future). The last category is *ad hoc teams.* Team members of these teams will work together only temporary. Therefore, they do not have shared past experiences and do not expect to work together in the future for a long time (McGrath, as cited in Alge et al., 2003).

In present study, it was expected that the extent to which team members have a shared past might influence the way in which team members coordinate their tasks. It was expected that the more experienced a team is and the better the team members know each other, coordination is based more on shared mental models and in this way, the need of other coordination mechanisms is reduced.

2.2 Virtual teams

The technological advances in the last decennia resulted in large changes in team work. Due to the development of electronic media work structures have been changed in the last years and more and more work is done by virtual teams (Alavi & Tiwana, 2002; Alge et al., 2003; Marks et al., 2005; Saunders & Ahuja, 2006). A virtual team can be defined as a group of people who work interdependently with a shared purpose across space, time, and organization boundaries using technology (Lipnack & Stamps, 2000). According to O'Leary (2003), virtual teams can be dispersed on three dimension: spatial (the geographical distance between team members), temporal (the degree to which team members work at different times, for example due to different time zones) and configurational (the number of work places and the number of team members at each workplace).

Virtual teams have several benefits compared to non-virtual, face-to-face-teams. Because physical location of people does not have to be taken into account when selecting people, the people with the most expertise can be selected. Next to that, virtual teams can work around the clock when team members are located in different time zones, which can lead to big time savings (Van der Kleij, 2007).

Although virtual teams have benefits, they can encounter problems as well. Thompson and Coovert (2006) describe three categories of barriers for effective team work in virtual teams: 'failure to develop effective interpersonal relationships', 'communication mishaps', and 'lack of awareness of team members' endeavors'. Due to the dispersion of team members, team members communicate less social information, like social context cues, voice volume and physical appearance. The absence of this information results in a failure of the development of effective interpersonal relationships, for example because of a decreased team commitment, cohesion, trust and satisfaction (Thompson & Coovert, 2006). The second barrier is an increase in the occurrence of communication mishaps as a result of the communication channels used in virtual teams. In face-to-face settings, a wide range of behaviors can be used to communicate (for example body gestures) and speakers immediately receive feedback on how their sent message is understood. As teams that work in virtual settings are not able to transmit all these kinds of information in the way it happens in face-to-face communication, communication mishaps may occur (Fussel & Benimoff, 1995). The third barrier is a lack of awareness of team members endeavors. In face-to-face teams, team members can see whether other team members are present, what they are doing. Even when explicit communication is missing, team members are still able to monitor the activities of each others and maintain awareness of each others endeavors. In virtual teams, team members cannot observe each other's activities (Thompson & Coovert, 2006). According to

Carroll, Rosson, Convertino, and Ganoe (2006) this information based on the observation of other team members, is necessary for effective teamwork. Team members have to be up to date about which other team members are present, what they know, what they expect and which tools and resources they can access. According to Kraut, Fussell, Brennan and Siegel (2002), task and team awareness helps to understand the progress of others' work and to determine which actions are required at which moment; it is needed for the coordination of team work.

Present study focused on distributed teams and examined the possibilities of supporting these teams with an observability display. An observability display might help to overcome the barriers described by Thompson and Coovert (2006). In this way, distributed team work can become more effective.

2.3 Coordination

Coordination is the process of managing dependencies among activities (Malone & Crowston, 1994). A *fit dependency* occurs when multiple activities together produce a resource. There is a *flow dependency* when multiple activities have to be performed in a specific order as one activity produces a resource that is required for a next activity. When multiple activities all use the same resource, this is called a *sharing dependency* (Malone et al., 1999). The more complex a task or the bigger the team, the more dependencies there are, which results in an increased need for coordination (Espinosa, Lerch, & Kraut, 2004).

Coordination can manifest itself in several ways, for example in *backing-up behavior.* Backing-up behavior is the shift of workload among team members in order to achieve balance during periods of high workload or pressure (Salas et al., 2005). If one team member has too much work to do, while others do not have a high workload at that moment, they can assist the busy team member. The frequency of these coordination behaviors predicts the performance of a team (Urban, Bowers, Franz, & Morgan, as cited in Bowers, Salas, Prince, & Branninck, 1992).

According to Salas et al. (2005), three coordination mechanisms contribute to the coordination of team work, as shown in Figure 2. *Closed-loop communication* is communication which includes that the receiver of the message clarifies with the sender of the message that the message is received in the way the sender intended it. Communication results in distributed information between team members and in continuous updating of the shared mental model (Salas et al., 2005). *Mutual trust*, the second coordination mechanism, is 'the shared perception that individuals in the team will perform particular actions important to its members and will recognize and protect the rights and interests of all team members engaged in their joint endeavor' (Webber, 2002). In a situation of mutual trust, team members feel safe to share information and are willing to accept and give backing-up behavior, as team members understand that this is for the good of the team (Nelson & Cooprider, 1996).

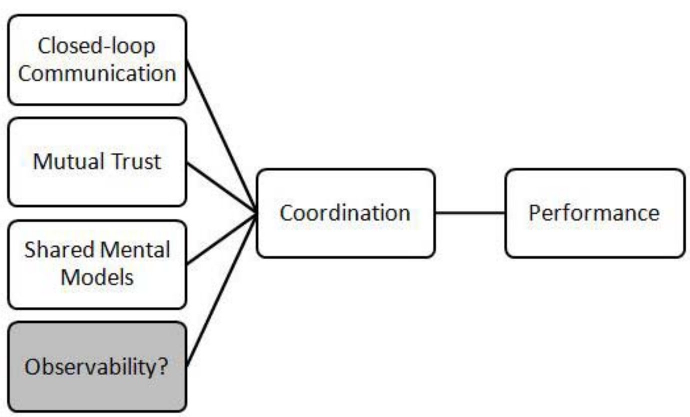

Figure 2: Coordination Mechanisms

Shared mental models, a shared understanding or representation of the team and task, give team members the possibility to form explanations for and expectations of the activities of other team members, which help team members to coordinate effectively (Cannon-Bowers, Salas, & Converse, 1993; Fransen, Kirschner, & Erkens, 2011; Mathieu, Heffner, Goodwin, Salas., & Cannon-Bowers, 2000; Stout, Cannon-Bowers, Salas, & Milanovich, 1999; Zaccaro, Ritman, & Marks, 2001). Especially in situations with high workload or time pressure, which make communication more difficult, shared mental models can help teams functioning because with shared mental models, team members can predict what others will do and which information and resources they need (Mathieu et al., 2000). Shared mental models can be divided in team-related and task-related mental models. The awareness of the functioning of a team and the expected behavior of the team and the individual team members in relation to each other belongs to team-related mental models. Task-related mental models focus on the materials and strategies that are needed to carry out the task successfully during teamwork. The shared mental models are continuously updated and become more accurate over time (Fransen et al., 2011). Teams that have not been able yet to develop shared mental models, for example the future teams described before, miss one of the three coordination mechanisms described by Salas et al. (2005). The present study focuses on a fourth coordination mechanism: observability, which was expected to compensate for a lack of shared mental models in future and ad hoc teams.

2.4 Observability

An observability display visualizes (information) elements that are non-observable without explicit effort because of a temporal or spatial boundary (De Greef et al., 2011). Observability displays show information which team members that work at the same place and time can observe about each other, but which team member can not observe when they work at different places or at different times (so called virtual teams). In distributed teams, the actions of other team members are not directly observable, which makes it much more difficult for distributed teams to make predictions about the activities other team members will perform in the future and thus coordinate actions. With use of an observability display, which shows the team members information about each other and their activities, the mutual predictability of team members increases and in this way, the coordination between team members might be supported (De Greef et al., 2011).

De Greef et al. (2011) showed that performance of teams was not influenced by the use of an observability display and that the perceived workload was higher. However, the display had a positive effect on backing-up behavior, one of the ways in which coordination may be manifested. Next to that, there was less explicit communication (one of the coordination mechanisms) when using an observability display. Therefore, it was concluded that coordination within virtual teams is influenced by the presence of an observability display.

Observability Elements

In order to design an observability display, one has to decide which observability information should be visualized on the display. Many studies have been done in the area of awareness displays and many different elements have been used on the displays. To combine this knowledge from previous research and to get an overview of the many possibilities when designing a display, an inventory has been made of the information elements that team members might want to know when working distributed (see Appendix A). This list could be used as a starting point when designing an observability display.

In order to categorize the list of observability elements, a trichotomy described by Bodemer and Dehler (2011) was used as starting point. Bodemer and Dehler divide awareness in *behavioral awareness* (awareness of the activities of others), *cognitive awareness* (awareness of the knowledge of others), and *social awareness* (awareness of the functioning about group as perceived by others). Gutwin and Greenberg (2002) use another division of awareness elements; a categorization of the elements based on the temporal scope.

They describe awareness information related to the *past* and information related to the *present*. However, as coordination is not only guided by information about the past and the present, but by future plans as well, *future* has been added to the two categories of Gutwin and Greenberg (2002). As both the categorizations seem to be useful, they were combined when categorizing the observability elements. Cognitive awareness about the present situation supports team members to form expectations about the possibilities and skills of others. On the other hand, behavioral awareness of the future will help team members to plan their actions.

The functionality of the different observability elements depends largely on the task a team has to work on and the dependencies which are important in this task. For example, during a task in which team members continuously change their location it might be useful that the observability display shows the location of other team members. However, when team members do not move during the task, this information is irrelevant. Therefore, when designing an observability display, one should focus on the coordination dependencies of the team task and choose observability elements that support managing these dependencies.

2.5 Task Complexity

Task Complexity is a concept that has been approached in many different ways as there is little consensus among researchers (Campbell, 1988). Campbell (1988) organizes the different approaches in three categories: task complexity as (a) a psychological, subjective, experience, (b) an interaction between task and person characteristics and (c) a function of objective task characteristics. Campbell proposes the last category and describes that complexity of a task is caused by an increase in information load, information diversity, or rate of information change. Robinson (2001) states that task complexity is the result of attentional, memory, reasoning and other information processing demands. The definition of task complexity used in this study, is based on Campbell (1988) and Robinson (2001). Task complexity is defined as the reasoning demands required to complete a task.

The complexity of a task can influence team work. An increased task complexity can result in conflicts in goals and tasks, which can influence team coordination (Xiao, Hunter, Mackenzie, Jefferies, & Horst, 1996). As more attention is needed for complex tasks, this can be at the expense of other tasks. Veltman and Jansen (2004) showed that when task demands increase, this can result in an increase of investing mental effort or a reduce of task goals. Sperandio (1971) showed that when workload of air traffic controllers increased, they change task strategies and reduce communication in order to keep the workload at a manageable level.

As the availability of an observability display during team work gives the team members an extra task, looking at and updating the display, and previous research of De Greef et al. (2011) showed that workload increased when an observability display was available, it is interesting to examine the relation between task complexity and use of the observability display. In this way, it can be investigated whether an observability display is useful for tasks of all complexity levels or not.

2.6 Present Study

De Greef et al. (2011) showed that observability information is useful for distributed teams. The purpose of present study was to further explore the concept of observability. In present study, the focus was on future teams and ad hoc teams, of which the team members do not have a shared past and therefore have not been able to get familiar with each other (McGrath, as cited in Alge et al., 2003). Working together distributed makes it difficult to develop effective interpersonal relationships, communicate without mishaps and stay aware of the endeavors of other team members (Thompson & Coovert, 2006). An observability display may support future and ad hoc teams overcoming the barriers of working together distributed and being unfamiliar to each other as a future team.

An important question is whether the role of an observability display changes when team members get to know each other over time and get familiar to each other. The first goal of present study is to investigate the effect of team experience on the use of an observability display and coordination within distributed teams.

Good coordination is needed for good performance. However, Xiao et al. (1996), Veltman and Jansen (2004), and Sperandio (1971) showed that if task complexity increases, task strategies change. Next to that, De Greef et al. (2011) showed that perceived workload increased when an observability display was available. It might be the case that the focus on the coordination process and thus the use of the observability display changes when tasks become more complex. The second goal of this study is to examine the effects of task complexity on the use of an observability display in order to determine whether tasks of each complexity level could be supported with an observability display.

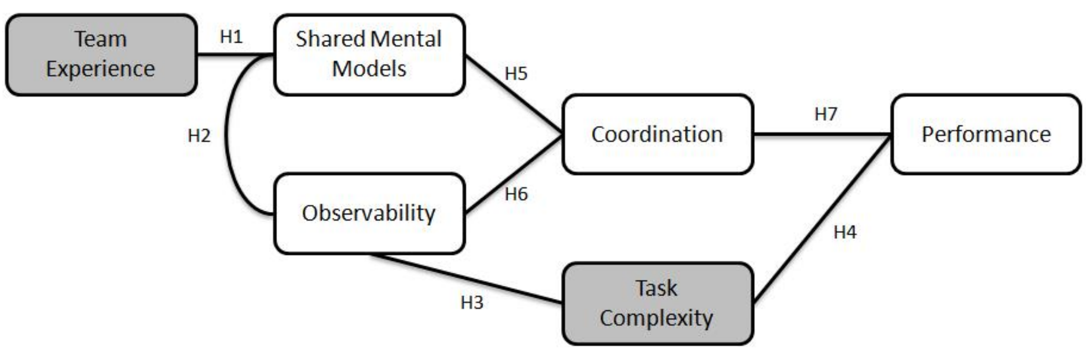

Figure 3: Research model

As depicted in Figure 3, several factors were expected to be related to the use of an observability display and coordination. Seven hypotheses were proposed.

Hypothesis 1: As a shared mental model develops over time (Bolstad & Endsley, 1999), it was expected that an increase of team experience would result in a better developed shared mental model.

Hypothesis 2: A well developed shared mental model decreases the need of other coordination mechanisms (Bolstad and Endsley, 1999). Therefore, it was hypothesized that the development of a shared mental model is negatively associated with use of the observability display.

Hypothesis 3: Based on Xiao et al. (1996) it was proposed that when task complexity increases, team members will focus more on task-related activities than on team-related activities. Therefore it was expected that use of the observability display is lower when performing high complexity tasks compared to low complexity tasks.

Hypothesis 4: As an increase in task complexity lowers performance (Maynard & Hakel, 1997), it was expected that an increased task complexity would result in a decreased performance.

Hypothesis 5: A shared mental model is one of the coordination mechanisms that contribute to coordination (Fransen, Kirschner, & Erkens, 2011). It was hypothesized that a better developed shared mental model would result in improved coordination between the team members (in case that the use of other coordination mechanisms does not decrease).

Hypothesis 6: As observability is proposed as a coordination mechanism, it was hypothesized that an increase of use of the observability display would result in improved coordination between the team members (in case that the use of other coordination mechanisms does not decrease).

Hypothesis 7: As coordination is required for and predicts team performance (Urban et al., as cited in Bowers, Salas, Prince, & Branninck, 1992) it was hypothesized that improved coordination between the team members would result in an improved performance.

To find an answer to these hypotheses an experiment was designed in which a virtual team of three persons had to work together distributed on a Sudoku puzzle task. Several dependencies were included in the task in order to increase the need for coordination between the team members. The team members were unfamiliar to each other and, as they did not have a shared past, could therefore be seen as future or ad hoc teams. Teams had to work on Sudoku puzzles for several trials and the complexity of these trials varied. In this way, the effect of Team Experience and Task Complexity could be examined.

Chapter 3 Method

3.1 Participants

Forty-eight participants (20 men, 28 women, mean age = 23.44, *SD* = 3.02), recruited from the TNO participants database, took part in the experiment. Because of the complexity of the used task, participants were required to have a minimum education at college level. The participants were randomly assigned to one of 16 three-person teams, which were mainly mixed-gender. It was made sure that none of the team members knew each other prior to the experiment. Participants were paid €45 for participation. A €120 bonus was awarded to the best performing team in order to enhance motivation. As teams did not change significantly on background variables (education, age, team experience, Sudoku experience), these variables are not discussed further.

3.2 Task

For the experiment, a team task was required in which team members had to work together from different locations. As the role of observability was to be examined, there had to be a strong need for coordination between the team members. As the influence of team experience was to be examined, the task had to be repeated for six trials. Therefore, several interchangeable versions of the task were required. To examine the effects of task complexity, the level of task complexity had to vary between versions of the task. As existing tasks did not meet these criteria, a new task was developed.

Teams of three persons worked together on a Sudoku puzzle task for six trials of 20 minutes. Sudoku puzzles are puzzles that consist of a 9x9 array of cells, which can be divided in 9 blocks of 3x3 cells. Some of these cells are filled with numbers and goal is to fill in the missing numbers according to the rule that in each row, column and 3x3 block, the numbers 1 to 9 have to be placed once (Lee, Goodwin, & Johnson-Laird, 2008). As the focus was on distributed teams, the three team members were located in different rooms. Teams had to try to maximize their score, by solving as many Sudoku puzzles as possible within twenty minutes.

As one of the goals was to examine the role of observability as coordination mechanism, there had to be a need for coordination between the team members. Therefore, several dependencies were integrated in the puzzle solving task, based on the dependencies described by Malone et al. (1999). First of all there was a fit dependency, as the Sudoku puzzles had different colors (red, blue, and yellow) and the team could earn bonus points by handing in solved Sudoku puzzles in sets of three, consisting of specific color combinations. The color combination (for example: one red and two yellow puzzles) was different for each set. For each correct handed in set of puzzles, the team earned 3 bonus points. Each trial, each team member received a sheet on which the color combinations were displayed (see Appendix B). In order to hand in correct sets of Sudoku puzzles participants had to coordinate their work on the different Sudoku puzzle colors.

Next to that, there was a flow dependency, as filled in cells of one Sudoku puzzle could serve as a basis for a next Sudoku. Although it was possible to solve a Sudoku puzzle without the information of the previous Sudoku, it might have been possible to save time by copying cells. Within each color of Sudoku puzzles, there was an order in which the Sudoku puzzles should be made to benefit from copying cells. The numbers of nine cells could be copied to the next Sudoku puzzle provided that the new puzzle followed to the previous puzzle, as shown in Figure 4. Each trial, participants received a sheet with the order information (see Appendix C).

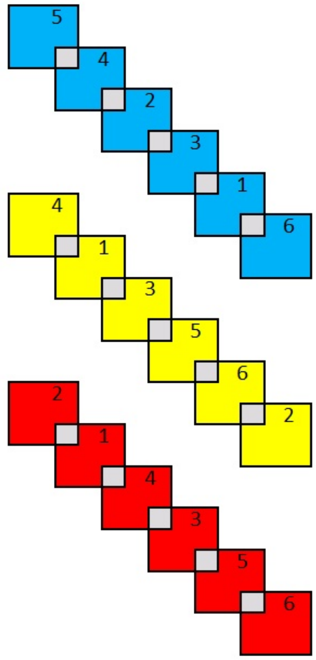

Figure 4: Order of Sudoku Puzzles

Furthermore, there was a sharing dependency, as there was a limited amount of time to solve the Sudoku puzzles. By solving puzzles as fast as possible, a maximum of puzzles could be solved within the limited time of twenty minutes. As the amount of finished puzzles partially determined the performance, the team had to work as fast as possible to maximize performance. Again, participants had to coordinate their work.

Within each trial, the complexity of the Sudoku puzzles varied: the blue and yellow puzzles had the same complexity level; the red puzzles were a bit more complex. The team could earn two points for each solved red Sudoku puzzle and one point for each blue or yellow puzzle. The Sudoku puzzles were printed on paper and located in front of the rooms of the participants, sorted by color. Participants could pick one of the Sudoku puzzles and solve it in their own rooms.

Participants were able to know what the other team members were doing, using the observability display. Based on the information on the display, participants could decide what to do. For example, one of the possibilities of the observability display was that a participant could indicate which color of Sudoku puzzle he or she would start working on when his/her current Sudoku puzzle was finished. In this way, participants could predict and anticipate on each others actions and coordinate team work.

At the beginning of each trial, the experimenter gave each participant a paper with the order-information and color combinations of the puzzles in that trial. Participants received an envelope which contained a short questionnaire concerning situation awareness. Each trial started with a new set of Sudoku puzzles and new information papers.

3.3 Procedure and dependent measures

Participants received a general oral instruction about the experiment. They were told that the purpose of the experiment is to study teamwork in virtual teams and that they have to try to maximize their performance. After participants filled in an informed consent, a detailed written explanation of the task was given and the observability display was explained to the participants. Participants then were situated in the different rooms to practice with the observability display and to fill in a questionnaire pertaining to background information (age, gender, education, experience with Sudoku puzzles, teamwork, and so forth). Subsequently, participants were given some time to practice a Sudoku puzzle and more explanation about solving Sudoku puzzles was given when needed.

Continuously, the experiment trials were started. During six trials of 20 minutes, participants had to work on the puzzle task. As the influence of task complexity was to be examined, there were three high complexity trials and three low complexity trials for each team. Two measures of Shared Mental Model were used, as multiple studies show that multiple shared mental models exist: team related as well as task related (Cannon-Bowers et al., 1993); Klimoski and Mohammed, as cited in Mathieu et al., 2000; Rentsch & Hall, as cited in Mathieu et al., 2000). During each trial, there was a freeze moment in which the puzzle task was paused and the participants had to fill in a questionnaire pertaining to their situation awareness, the task related part of the factor ‘Shared Mental Model’ in Figure 3. The questionnaire consisted of 5 items pertaining to the current status of the work of other team members. Examples of questions: how long is person A working on his puzzle? what is the color of the puzzle person B is working on? how many puzzles has person C solved? The more questions answered correctly by the participants, the higher the situation awareness. Six different versions of the questionnaires were used in counterbalanced order. The questions of the questionnaire can be found in Appendix D. The freeze moment was between 7 and 13 minutes after the start of the block, indicated to the participants with a sound signal. During the freeze moment, the observability display was not visible. The order of moments at which the task was frozen, was counterbalanced among the teams.

After each trial, participants had to fill in a questionnaire pertaining to task complexity, team coordination, team related shared mental model, perceived usefulness and ease of use of the observability display. All questions were translated to Dutch and can be found in Appendix D.

Perceived task complexity, related to the factor ‘Task Complexity’ in Figure 3, was measured in order to control whether the manipulation of task complexity succeeded. Task complexity was measured by 3 questions, derived from a questionnaire developed by Maynard and Hakel (1997). Participants had to rate the items ‘I found this to be a complex task’, ‘This task was mentally demanding’, ‘This task required a lot of thought and problem-solving’ on a 7-point Likert type scale labeled from *strongly disagree* to *strongly agree* (3 items, Cronbach’s $\alpha = 0.88$).

As Task Complexity can be defined in multiple ways, a second scale was used to check the manipulation of Task Complexity. The Rating Scale Mental Effort (RSME) (Zijlstra, 1993) is a one-dimensional scale with ratings from 0 to 150 on which participants have to respond to the question ‘how much effort did it cost you to fulfill the task?’. The scale has nine descriptive indicators along its axis (e.g., 12 corresponds to not effortful, 58 to rather effortful, and 113 to extremely effortful).

To measure a team mental model, as part of the factor ‘Shared Mental Model’ in Figure 3, a measure based on Austin (2003) was used. Participants were asked to fill in a questionnaire pertaining to their own skills (solving sudokus, coordinating tasks, contribute to making color combinations) and the skills of the other team members after each trial. On a 7-point Likert type scale labeled from *very bad* to *very good*, participants had to rate their own skills and those of others. The average of the variance in ratings on each item was calculated per trial and used as a measure of shared team mental model. The lower the variance between skill judgments, the better developed the shared mental model (3 items, Cronbach’s $\alpha = 0.73$).

Perceived coordination within the team, related to the factor ‘Coordination’ in Figure 3, was measured after each trial with an adjusted version of the Inter-team Coordination Questionnaire of Hoegl, Weinkauf, and Gemuenden (2004). Participants had to respond to four items (‘Activities were well coordinated with other team members’, ‘Coordination with other team members went smoothly’, ‘Double and overlapping activities were avoided’ and ‘Conflicts with other team members were settled quickly’) on a 7-point Likert type scale labeled from ‘*strongly disagree’* to ‘*strongly agree’* (4 items, Cronbach’s $\alpha = 0.92$).

Perceived Usefulness of the observablity display, related to the factor ‘Observability’ in Figure 3, was measured after each trial with 3 questions derived from the Perceived Usefulness and Ease of Use questionnaire of Davis (1989). Participants had to respond to the items ‘ The Observability Display is useful’, ‘The observability display gives insight to the team process’ and ‘ The Observability Display keeps me up to date effectively about relevant progress on the task’ on a 7-point Likert type scale labeled from ‘*strongly disagree’* to ‘*strongly agree’* (3 items, Cronbach’s $\alpha = 0.78$).

Ease of Use of the observability display, related to the factor 'Observability' in Figure 3, was measured after each trial with two questions derived from the Perceived Usefulness and Ease of Use questionnaire of Davis (1989). Participants had to respond to the items 'The Observability Display is easy to master' and ' The Observability Display is easy to use' on a 7-point Likert type scale labeled from '*strongly disagree'* to '*strongly agree'* (2 items, Cronbach's $\alpha = 0.73$).

At the end of each trial, the experiment leader collected the Sudoku puzzles, information forms and questionnaires of that trial and distributed the materials for the next trial. Performance of the team in the trail was noted.

Two performance measures were used as indication of the factor 'Performance' in Figure 3. The number of complete puzzles per team per trial was used as an indication of the Sudoku skills of the team. The other performance measure was the score, the amount of points, per team per trial. For each blue or yellow puzzle, the team received one point, for each red puzzle the team received two points. For each handed in set of puzzles that consisted of the right colors, the team received three bonus points. This score is not only influenced by the Sudoku skills of the team but also by how well the team coordinates choosing puzzles, which influences the amount of bonus points the team earned. The performance measures correlated significantly, $r_s = 0.98$, $p < .01$.

After the third trial, participants had a 10-minute break in their own rooms. After the six trials, participants were thanked for their cooperation.

3.4 Apparatus

Four rooms were used for the experiment. In three rooms, a participant was situated and in the fourth room, the experimenter was situated. In each participant room, a desk was placed as well as a computer, see Figure 5. The computer screen showed the observability display, as shown in Figure 6 and Appendix E. Input to the observability display could be given by the participants with use of the mouse and keyboard. In the experimenter room, the experimenter was able to monitor activity in the participant rooms with use of video cameras.

Figure 5: Participant room

The observability display gave participants information about the other team members. In this way, participants could adapt their work to the activities of the other team members and the activities could be coordinated. As described above, an observability display can show an enormous amount of information elements to team members but the usability of the elements depend on the coordination dependencies in the task.

To support managing the fit dependency, delivering sets of Sudoku puzzles of the right color, participants have to know which colors of puzzles have been made. In the list of observability elements, this information is behavioral awareness of the past about others' actions. The progress bar showed which puzzles were solved in the past and which puzzles are worked on at the moment.

The intention of the participants was displayed on the screen to support managing the fit dependency as well. With this information – behavioral awareness of the future –

participants knew which color of Sudoku puzzles the other participants were planning to work on after finishing their puzzle.

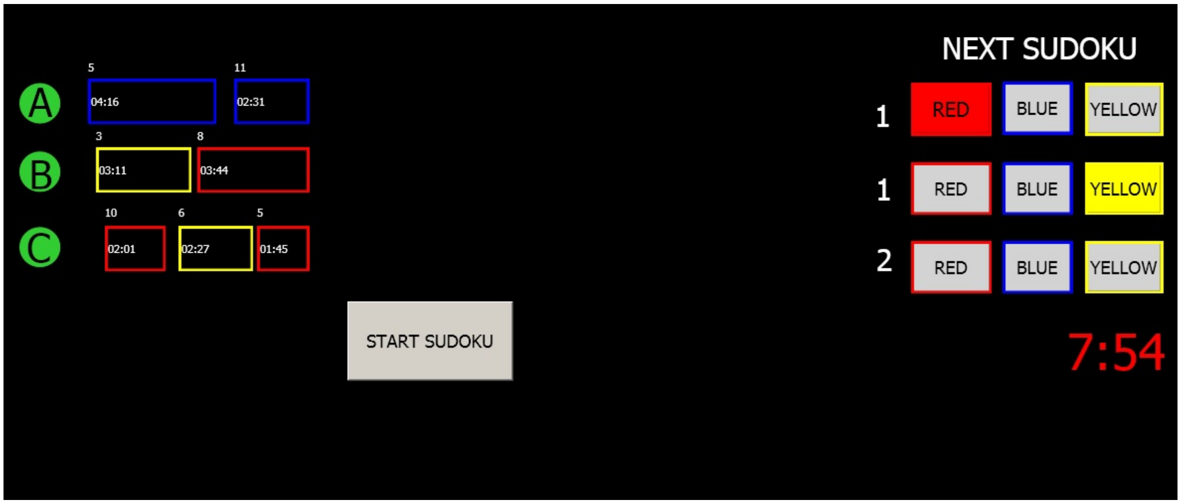

Figure 6: Observability Display

To support managing the flow dependency, solving Sudoku puzzles in a specific order, behavioral awareness information about the past was presented on the screen: the numbers of the puzzles participants worked on was displayed above the progress bars.

The display showed how long the team has been working on the task, in order to support managing the sharing dependency of a limited amount of time. In the list of observability elements, this information about the deadlines of the team and the importance of specific tasks belongs to behavioral awareness of the present. This information could support selecting a color of puzzle to work on.

The progress bar provides not only behavioral awareness to the participants, but cognitive awareness as well. The more time a team members needs to solve a puzzle, the longer the bar. In this way, awareness information about the abilities and skills of the team members was presented on the display.

Input for the screen was given by the participants. Intention could be updated by pressing a button that corresponds to the color of the Sudoku puzzles they are going to solve next. Team members could only indicate their own intention; they were not able to select a next color for another team member. On each display was a button which participants had to press when they started or finished a Sudoku. If the participants pressed the start-button, they were requested to fill in the number of the puzzle and press enter. A new bar then appeared on the screen, the color of the bar was identical to the color selected in the intention-part of the display. If no color was selected by a team member, the bar became white. As long as a participant was working on a puzzle, the bar became wider, until the stop button was pressed.

Participants had to click with the mouse in order to make the display visible for 20 seconds, and then the screen became grey again. The number of mouse clicks in order to make the display visible was logged automatically and used as measure for frequency of use of the observability display.

3.5 Design

A within-subject repeated measures design was used with Experience (block 1, 2 and 3) and Task Complexity (low, high) as independent variables. The task existed of 6 trials, divided in three blocks. Each block consisted of 1 trial with high task complexity and 1 trial with low task complexity. A pretest has been executed in order to select Sudoku puzzles. For the high complexity trials, in which the reasoning demands had to be higher than in the low complexity trials, Sudoku puzzles have been selected that take more time to solve than puzzles for the low complexity trials.

The order of low and high complexity trials within block 3-6 was counterbalanced among teams. In block 1, each team started with a low complexity trial followed by a high complexity trial in order to eliminate a possible entrainment effect. Social entrainment is the concept of altering social patterns by external conditions and the persistence of such rhythms over time (Kelly & McGrath, 1985). As the complexity level of the first trial could influence for example the team's strategy, this could lead to differences between teams based on the complexity level of the first trial. Therefore it was decided to let each team start with the same complexity level.

3.6 Data analysis

A 2 x 3 General Linear Model Repeated Measures design was used for data analysis, with Experience (block 1, block 2, block 3) and Task Complexity (low, high) as within-group variables. Data were aggregated and analyzed at the team level in order to not violate the assumption of independent team members (Kenny, 1998). Data of two subsequent trials were combined into blocks, in this way the three blocks contained the same amount of data from low as high complexity trials.

Main effects of Experience and Task Complexity and the interaction effect of Experience x Task Complexity were examined. Post-hoc multiple comparisons were done using Least Significant Differences comparisons. Although this test does not correct for the number of tests performed, this test was used because of the limited power as 16 teams participated in the experiment.

As the use of display could be influenced by the number of puzzles made, it was tested whether the number of puzzles should be used as covariate when analyzing the use of the observability display. MANOVA Wilks's lambda showed that there was no significant relation between the use of the observability display and the number of puzzles made, $F(36,20) = 1.16$, $p > .5$. Therefore analyses have been done without covariate.

Correlations between dependent variables were calculated using Spearman's rho, as the Kolmogorov-Smirnov test indicated that not all of the variables met the assumption of normality.

Chapter 4 Results

Results of the experiment will be discussed per variable. An overview of mean scores per block and task complexity level, effects of experience and task complexity level, and correlations between the dependent variables can be found in Table 1, 2 and 3 on page 44, 45 and 46.

4.1 Manipulation check Task Complexity

Rating Scale Mental Effort

Repeated-measures ANOVA showed no significant effect of Experience on RSME, $F(2,30) = 1.03$, $p > .05$, $\eta_p^2 = 0.06$. Mental effort reported after high complexity trials (M = 76.80, SD = 8.47) did not differ significantly from mental effort reported after low complexity trials (M = 74.04, SD = 8.33), $F(1,15) = 3.59$, $p > .05$, $\eta_p^2 = 0.19$. No significant interaction effect of Experience x Task Complexity was found, $F(2,30) = 1.12$, $p > .05$, $\eta_p^2 = 0.07$.

Questionnaire Task Complexity

Repeated-measures ANOVA showed no significant effect of Experience on Task Complexity scores, $F(2,30) = 0.42$, $p > .05$, $\eta_p^2 = 0.03$. Scores on the Task Complexity questionnaire were significantly higher after high complexity trials (M = 5.32, SD = 0.52) than after low complexity trials (M = 4.71, SD = 0.59, $F(1,15) = 32.91$, $p < .01$, $\eta_p^2 = 0.69$). A significant interaction effect of Experience x Task Complexity was found $F(2,30) = 4.90$, $p < .05$, $\eta_p^2 = 0.25$, see Figure 7. Post-hoc LSD comparisons showed that for each block, the scores of the Task Complexity questionnaire were significantly higher in high complexity trials than in low complexity trials (resp. $p < .01$, $p < .05$, $p < .05$). Within the high complexity trials, scores in block 1 were significantly higher than scores in block 3 ($p < .05$). No other significant differences between blocks within one complexity level were found.

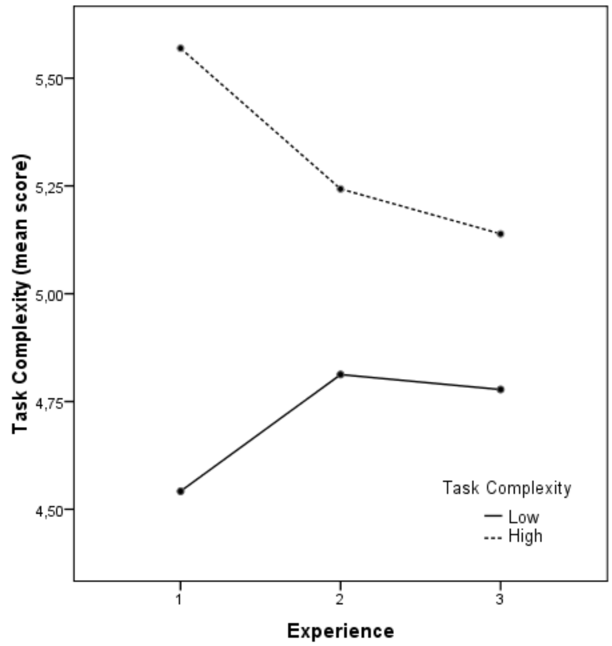

Figure 7: Mean scores on Task Complexity Questionnaire for each task complexity level (low, high) and level of experience (1, 2, 3)

4.2 Dependent variables

Performance – Number of puzzles

There was a significant effect of Experience on the number of puzzles made (block 1: $M = 2.32$, $SD = 0.51$; block 2: $M = 2.75$ $SD = 0.69$, block 3: $M = 2.91$, $SD = 0.73$, $F(2,30) = 8.05$, $p < .01$ $\eta_p^2 = 0.35$). Post-hoc multiple comparisons using an LSD-test showed that the number of puzzles made in block 1 was significantly lower than in block 2 (mean difference = 0.43, $p < .01$) as well as in block 3 (mean difference = 0.58, $p < .01$). The number of puzzles in block 2 was not significantly lower than in block 3 (mean difference = 0.16, $p > .5$). The number of puzzles made in low complexity trials ($M = 3.52$, $SD = 0.76$) was significantly higher than the number of puzzles made in high complexity trials (*M* = 1.80, *SD* = 0.42, $F(1,15) = 162.88$, $p < .01$, $\eta_p^2 = 0.92$). No significant interaction effect of Experience x Task Complexity was found, $F(2,30) = 0.09$, $p > .05$, $\eta_p^2 = 0.01$.

Performance – Score

There was a significant effect of Experience on the scores (amount of points) (block 1: *M* = 14.69, *SD* = 3.42; block 2: *M* = 17.63, *SD* = 5.01; block 3: *M* = 18.50, *SD* = 5.03, $F(2,30) = 6.17$, $p < .01$, $\eta_p^2 = 0.29$). Post-hoc multiple comparisons using an LSD-test showed that scores in block 1 were significantly lower than scores in block 2 (mean difference = 2.94, $p < .05$) and scores in block 3 (mean difference = 3.81, $p < .01$). Scores in block 2 were not significantly lower than scores in block 3 (mean difference = 0.88, $p > .05$). The scores in low complexity trials (*M* = 22.75, *SD* = 4.94) were significantly higher than the scores in high complexity trials (*M* = 11.13, *SD* = 3.03), $F(1,15) = 180.66$, $p < .01$, $\eta_p^2 = 0.92$. No significant interaction effect of Experience x Task Complexity Block was found, $F(2,30) = 0.11$, $p > .05$, $\eta_p^2 = 0.01$.

Intra Team Coordination

There was a significant effect of Experience on ITC scores, $F(2,30) = 13.38$, $p < .01$, $\eta_p^2 = 0.47$. Post-hoc LSD tests showed that ratings of coordination in block 1 (*M* = 4.52, *SD* = 0.57) were significantly higher than in block 2 (*M* = 4.94, *SD* = 0.67) and block 3 (*M* = 5.17, *SD* = 0.60) (Block 1-2: mean difference = 0.43, $p < .01$; block 1-3: mean difference = 0.65, $p < .01$). Ratings in block 2 were not significantly lower than in block 3 (mean difference = 0.22, $p > .05$).

A significant effect of Task Complexity on Intra Team Coordination scores was found, $F(1,15) = 6.86$, $p < 0.05$, $\eta_p^2 = 0.31$. ITC scores were higher after low complexity trials (*M* = 4.98, *SD* = 0.60) than after high complexity trials (*M* = 4.78, *SD* = 0.53).

The interaction effect of Experience x Task Complexity approaches significance, $F(2) = 3.22$, $p = 0.054$, $\eta_p^2 = 0.18$, see Figure 8. Post-hoc LSD comparisons showed that within each block, there were no significant differences between low and high complexity trials (all p's >.5). Within the low complexity trials, ratings in block 1 were significantly lower than ratings in block 2 ($p < 0.01$) and block 3 ($p < .01$). Other differences between blocks within each complexity level did not reach significance (all p's > .1)

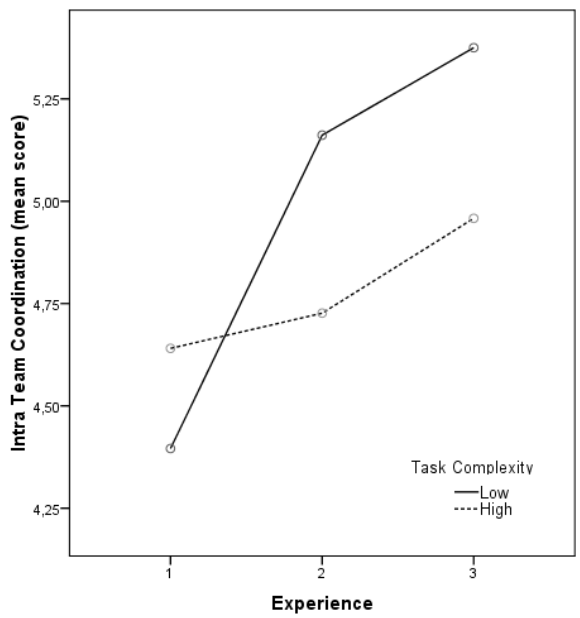

Figure 8: Mean scores of Intra Team Coordination for each task complexity level (low, high) and level of experience (1, 2, 3)

Ease of use

As Mauchly's test indicated that the assumption of sphericity had been violated when analyzing the effect of Experience ($\chi^2(2) = 7.82$, $p < .05$), the degrees of freedom were corrected for this analysis, using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.70$). A significant effect of Experience was found on the scores of the Ease of Use questionnaire, $F(1.40,21.01) = 8.09$, $p < .01$, $\eta_p^2 = 0.35$. Post-hoc LSD comparisons showed that ease of use scores of block 1 (*M* = 5.88, *SD* = 0.35) were significantly lower than scores of block 2 (*M* = 6.06, *SD* = 0.38), mean difference = 0.18, $p < .05$. Scores of block 1 were significantly lower than scores of block 3 (*M* = 6.16, *SD* = 0.42) as well (mean difference = 0.28, $p < .01$). Scores of block 2 were not significantly lower than scores of block 3 (mean difference = 0.10, $p > .05$).

Ease of Use scores did not differ significantly between low complexity trials (*M* = 6.02, *SD* = 0.38) and high complexity trials (*M* = 6.04, *SD* = 0.34), $F(1,15) = 0.11$, $p > .05$, $\eta_p^2 = 0.01$. No significant interaction effect of Experience x Task Complexity was found, $F(2,30) = 1.83$, $p > .05$, $\eta_p^2 = 0.11$.

Perceived usefulness

As Mauchly's test indicated that the assumption of sphericity had been violated when analyzing the effect of Experience ($\chi^2(2) = 11.35$, $p < 0.01$), the degrees of freedom were corrected for this analysis, using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.64$). No significant effect of Experience on Perceived usefulness scores was found, $F(1.29,19.29) = 0.94$, $p > .05$, $\eta_p^2 = 0.06$.

No significant effect of Task Complexity was found on the Perceived Usefulness scores, $F(1,15) = 3.22$, $p > .05$, $\eta_p^2 = 0.18$ and no significant interaction effect of Experience x Task Complexity was found, $F(2,30) = 3.12$, $p > .05$, $\eta_p^2 = 0.17$.

Use of the observability display

The use of the observability display was measured by logging how often participants clicked on the screen to make the display visible. As Mauchly's test indicated that the assumption of sphericity had been violated when analyzing the effect of Experience ($\chi^2(2) = 6.09$, $p = 0.048$), the degrees of freedom were corrected for the repeated measures ANOVA for this analysis, using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.74$).

The amount of clicks per block (block 1: $M = 14.69$, $SD = 0.23$; block 2: $M = 14.29$, $SD = 1.80$; block 3: $M = 14.20$, $SD = 2.42$) were not influenced significantly by Experience, $F(1.48,22.18) = 0.63$, $p > .5$, $\eta_p^2 = 0.04$. A significant effect of Task Complexity on the use of the observability display was found, $F(1,15) = 80.18$, $p < .01$, $\eta_p^2 = 0.84$. In the high complexity trials, the observability display was used less ($M = 12.63$, $SD = 1.96$) than in the low complexity trials ($M = 16.15$, $SD = 2.18$). No significant interaction effect of Experience x Task Complexity was found, $F(2,30) = 0.56$, $p > .5$, $\eta_p^2 = 0.04$.

Situation Awareness

Situation Awareness scores were not significantly influenced by Experience (block 1: $M = 3.43$, $SD = 0.44$; block 2: $M = 3.21$, $SD = 0.42$; block 3: $M = 3.44$, $SD = 0.49$), $F(2,30) = 1.48$, $p > .05$, $\eta_p^2 = 0.09$. In low complexity trials the situation awareness was significantly lower ($M = 3.19$, $SD = 0.31$) than in high complexity trials ($M = 3.53$, SD = 0.39), $F(1,15) = 11.79$, $p < .01$, $\eta_p^2 = 0.44$. No significant interaction effect of Experience x Task Complexity was found, $F(1.34,20.03) = 0.35$, $p > .05$, $\eta_p^2 = 0.02$ (corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.67$) as Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(2) = 9.64$, $p < .01$).

Shared Mental Model

There was no significant influence of Experience on deviation in the judgments of each other's skills (block 1: $M = 1.30$, $SD = 0.52$; block 2: $M = 1.30$, $SD = 0.58$; block 3: $M = 1.24$, $SD = 0.76$), $F(2,30) = 0.094$, $p > .05$, $\eta_p^2 = 0.01$. Deviations in the judgments of each other's skills were significantly higher after high complexity trials ($M = 1.48$, $SD = 0.65$) than after low complexity trials ($M = 1.08$, $SD = 0.45$), $F(1,15) = 13.01$, $p < .01$, $\eta_p^2 = 0.47$. No significant interaction effect of Experience x Task Complexity was found, $F(2,30) = 0.05$,

$p > .05$, $\eta_p^2 = 0.003$.

The correlation of Shared Mental Model and Display Use was calculated using Spearman's rho, $r_s = -.05$, $p > .05$. Other correlations are shown in Table 3 on page 45.

Table 1: Mean values and standard deviations of dependent variables

	Experience						Task Complexity			
	Block 1		Block 2		Block 3		Low		High	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
RSME	76.05	4.47	76.54	9.82	73.68	10.35	74.04	8.33	76.80	8.47
Task Complexity	5.06	0.55	5.03	0.62	4.96	0.54	4.71	0.59	5.32	0.52
Puzzles	2.32	0.51	2.75	0.69	2.91	0.73	3.52	0.76	1.80	0.42
Score	14.69	3.42	17.63	5.01	18.50	5.03	22.75	4.94	11.13	3.03
ITC	4.52	0.57	4.94	0.67	5.17	0.60	4.98	0.60	4.78	0.53
Ease of Use	5.88	0.35	6.06	0.38	6.16	0.42	6.02	0.38	6.04	0.34
Perceived Usefulness	5.96	0.34	5.99	0.34	6.07	4.22	5.96	0.34	6.04	0.32
Display Use	14.69	0.23	14.29	1.80	14.20	2.42	16.15	2.18	12.63	1.96
Situation Awareness	3.43	0.44	3.21	0.42	3.44	0.49	3.19	0.31	3.53	0.39
SMM	1.30	0.52	1.30	0.58	1.24	0.76	1.08	0.45	1.48	0.65

Table 2: Summary of results of repeated measures ANOVA

	Experience			Task Complexity			Experience x Task Complexity		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
RSME	1.03	0.37	0.06	1.59	0.08	0.19	1.12	0.34	0.07
Task Complexity	0.42	0.66	0.03	32.91	0.00 **	0.69	4.90	0.01 **	0.25
Puzzles	8.05	0.00 **	0.35	162.88	0.00 **	0.92	0.09	0.92	0.01
Score	6.17	0.01 **	0.29	180.66	0.00 **	0.92	0.11	0.90	0.01
ITC	13.38	0.00 **	0.47	6.86	0.02 *	0.31	3.22	0.05	0.18
Ease of Use	8.09	0.01 **	0.35	0.11	0.75	0.01	1.83	0.18	0.11
Perceived Usefulness	0.94	0.37	0.06	3.22	0.09	0.18	3.12	0.06	0.17
Display Use	0.63	0.50	0.04	80.18	0.00 **	0.84	0.56	0.58	0.04
Situation Awareness	1.48	0.24	0.09	11.79	0.00 **	0.44	0.35	0.62	0.02
SMM	0.09	0.91	0.01	13.01	0.00	0.47	0.05	0.96	0.00

Table 3: Correlation Matrix

	Variable	1	2	3	4	5	6	7	8	9	10
1	RSME	-									
2	Task Complexity	.44 **	-								
3	Performance - Puzzles	-.29 **	-.53 **	-							
4	Performance - Score	-.37 **	-.55 **	.98 **	-						
5	ITC	-.30 **	-.04	.36 **	.37 **	-					
6	Ease of Use	-.32 **	-.11	.13	.17	.35 **	-				
7	Perceived Usefulness	-.27 **	-.01	-.09	-.11	.35 **	.53 **	-			
8	Display Use	-.07	-.25 *	.51 **	.49 **	.08	.18	-.15	-		
9	Situation Awareness	-.06	.22 *	-.23 *	-.25 *	-.04	.08	.17	.05	-	
10	Shared Mental Model	.24 *	.35 **	-.31 **	-.31 **	-.07	.13	.12	-.05	.05	-

*$p < .05$. ** $p < .01$.

Chapter 5 Discussion

The goal of present study was to examine the effects of team experience and task complexity on the use of an observability display and team coordination. Working in a distributed team can be difficult because of, among other elements, the lack of awareness of activities of other team members (Thomson & Coovert, 2006). De Greef et al. (2011) showed that an observability display increases the activity awareness of distributed team members, but that perceived workload increased. However, it was unclear what the effect of team experience on the use of an observability display and coordination was and in which way task complexity interferes with the use of an observability display and coordination. In order to examine these effects, an experiment was conducted in which distributed teams had to work together on a puzzle task with use of an observability display.

The Task Complexity questionnaire and Rating Scale Mental Effort were used to examine whether the manipulation of task complexity was succeeded. The Task Complexity questionnaire showed that the high complexity trials were perceived as more complex than the low complexity trials. The Rating Scale Mental Effort did not show a significant difference between high and low complexity trials. Though, Kirschner (2002) and Paas, Tuovinen, Tabbers, & Van Gerven (2003) describe mental effort as the cognitive capacity actually allocated to a task and one can imagine that solving a few high complexity Sudoku puzzles requires in total the same cognitive capacity as solving many low complexity puzzles. This could have resulted in not finding a significant difference in RSME scores between low and high complexity trials.

Moreover, the hypothesis concerning the negative relation between task complexity and performance (H4) is supported by the results. Performance (number of puzzles as well as score) was higher in low complexity trials than in high complexity trials. As the Task

Complexity questionnaire did show a significant difference between high and low complexity trials and performance differed significantly between both task complexity levels, it was concluded that the manipulation of Task Complexity was successful.

The main findings of this study were that team experience did not influence the use of an observability display but did influence coordination. Coordination ratings improved as team experience increased. The use of an observability display is influenced by task complexity: in low complexity trials, the display was used more than in high complexity trials. Coordination ratings were influenced by task complexity as well, as ratings of coordination were higher after low complexity trials compared to high complexity trials. These results are in line with Sperandio (1971) and Veltman and Jansen (2004), who describe that task strategies change in situations of increased demands, and Xiao et al. (1996) who describe that an increased task complexity leads to conflicts in goals and tasks. Team members have to divide their attention between the puzzle task and coordination. In high complexity tasks, solving the puzzle had more priority which resulted in a decreased use of the observability display.

Several hypotheses were proposed, including the role of shared mental models. In the following paragraphs, these hypotheses will be discussed.

It was expected that an increase of team experience would result in the development of a shared mental model (H1). Shared mental model was measured with a task related questionnaire during each trial and a team related shared mental model questionnaire after each trial. Measuring situation awareness is difficult, and this was experienced during this study as well. Doubt was raised about the validity of the task related questionnaire with questions about the information on the observability display. The more information displayed on the screen, the more difficult it is to answer the questions correctly. As participants completed more puzzles in the low complexity trials, more information was shown on the display in this condition and therefore it was more difficult to answer the questions during these trials. This resulted in less correct answers in the low task complexity condition compared to the high complexity trials. Because of this confounding influence of amount of information on the display, it was decided to reject the situation awareness questionnaire as measure of shared mental model.

Results of the second shared mental model measure, the deviation in participants' judgments of each other's skills, cannot confirm the hypothesis as it did not show an increase of shared mental model over time. Literature of shared mental models shows that measures of shared mental model are very comprehensive and time-consuming (Mathieu et al., 2000; Stout et al., 1999). Because of the limited time available during the experiment, it was decided to use a more basic, less time consuming, measure. This might have resulted in not finding an increase in shared mental model. Next to that, one could argue whether the four hours the experiment took, were enough to develop a shared mental model. According to Lim and Klein (2006), lab experiments are probably long enough for team members to develop a shared mental model of the task, but that the time is too limited to develop a shared mental model of the team. The development of a shared mental model probably takes more than four hours, which resulted in not finding an increase in shared mental model in this study. Because of these two reasons, it is difficult to draw conclusions about the role of shared mental model during the experiment.

A positive effect of shared mental model on coordination was expected (H5). As the measures of shared mental model indicated no increase of shared mental model, it is not possible draw conclusions about the effect of shared mental model on coordination. As team experience was hypothesized to result in a shared mental model, one could look at the effect of team experience on coordination. A positive effect of team experience on coordination was found. However, results of present experiment cannot explain the effect of shared mental models on coordination.

It was expected that an increased shared mental model would result in a decrease of the use of the observability display (H2). As the results do not indicate an increase of shared mental model over time, it is difficult to draw conclusions about this hypothesis. Therefore, conclusions should be restricted to the effect of team experience on the use of the observability display. Team experience did not influence the use of the observability display, as the frequency of display use was equal in all the blocks. This might indicate that the fact that team members get to know each other when working together, does not replace the need of an observability display and that an observability display can be useful for future and ad hoc teams, as well as for teams of which the team members are familiar to each other.

It was hypothesized that an increase of the use of observability information would result in an improved coordination (H6). Although the use of the observability display remained constant over time, rating of coordination increased over time. As the ratio between display use and coordination changes over time (relatively less display use is needed for coordination), it could be concluded that the efficiency of display use increases over time. The interaction effect of experience x task complexity on coordination rates approached significance. The increase in coordination rates can be found mainly in the low complexity condition. This indicates that an observability display supports coordination mainly in low complexity tasks.

The hypothesis concerning the positive effect of coordination on performance (H7) can be supported by the results of the experiment. Ratings of coordination as well as performance increased significantly over time and both measures of performance (score as well as the number of puzzles) correlate very strongly with the ratings of coordination (both p's $< .01$). There is however a possibility that the increase in performance is not caused by an increased coordination, but by a learning effect. Scores of the Ease of Use of the observability display increased significantly over time. However, Ease of Use did not correlate significantly with both performance measures (both p's > .1). Moreover, participants indicated already in the beginning of the experiment that it was not difficult at all to use the observability display. It was tried to prevent a learning effect in solving Sudoku puzzles to occur by letting participants practice with Sudoku puzzles. Despite this practice phase before the test blocks, it cannot be ruled out that a learning effect influenced the results.

Results of present study are in line with previous research. Present study showed that coordination improves as a result of team experience. Other studies showed as well that coordination in experienced teams was better than in teams with unfamiliar team members (Hollenbeck, Ilgen, LePine, Colquitt, & Hedlund, 1998, as cited in Alge Wiethoff Klein, 2003; Mathieu et al., 2000).

The finding of more display use and higher coordination rates in low complexity tasks compared to high complexity tasks is in line with studies of Sperandio (1971), Veltmand and Jansen (2004) and Xiao et al. (1996), who describe the influence of task complexity and task demands on task strategies. De Greef et al. (2011) showed that workload increased when an observability display was available. Task complexity and tasks demands were higher in high complexity trials compared to low complexity trials, which resulted in team members focussing more on the task than on use of the observability display.

The finding that the use of observability information remained constant over time, seems to be not in line with other literature. Based on the literature, which states that shared mental models develop over time, one would expect that that the use of an observability display would decrease over time as shared mental models would be used as coordination mechanisms. However, as described before, it might be that the duration of the experiment was too short to develop shared mental models and therefore, they could not be used as coordination mechanism instead of the observability display.

Although some of the results of present study are found in previous studies as well, present study combined the manipulation of task complexity and team experience. In this way, the interaction between these two factors could be examined, which has not been done in previous research Present study expanded current knowledge of team work in virtual settings, by showing that coordination rates improve as team experience increases, but that this effect can be found only in low complexity tasks.

Future research should take into account several aspects. First of all, it turned out that measuring shared mental model is more difficult than expected. For this study, two quick measures have been used as an indication of shared mental model. Given the fact that shared mental model is a very broad concept, the used measures might have been too narrow, especially because one of the two measures could not be used for analysis (as there was a confounding influence of the amount of information on the observability display). To examine the influence of shared mental model on the use of an observability display, it would therefore be recommended to use a more accurate measure of shared mental models. Next to that it would be recommended to increase the duration of the experiment as it might be that more time is needed for a team to develop a team shared mental model. Present study showed an effect of team experience on display use and coordination but has not been able to conclude what the role of shared mental models is. This could be examined in a future experiment.

An important characteristic of this task was the focus on teams that do not have a shared past. Because of this, it was not possible to let participant teams practice the experimental task, as this would give the team members a shared history before starting the task. Not practicing the task may have led to a learning effect during the experimental task, which distorts the results. Although the improved performance of the teams probably is caused by an increased coordination, future research should try to find a solution for this problem. In this way, the eventual influence of a learning effect can be ruled out.

Another aspect which is important to take into account in future research is the fact that the use of the observability display is influenced by the kind of information that is shown on the display. If the information on the observability display supports coordination but is not required, the use of the display and the effect of team experience on use of the display will be different compared to situations in which the information on the display is required for coordination. If participants can only be updated of information by looking at the observability display and a shared mental model does not support this awareness, this means that use of the observability cannot decrease over time. However, if a shared mental model can compensate for the information on the display, display use might decrease over time. Future research should therefore take into account that display use will depend on the task dependencies that are supported by the observability display.

Findings of this study have interesting practical implications. Results of this study show that distributed teamwork of future and ad hoc teams can be supported with an observability display. Developers of observability displays should first analyze the tasks for which a display has to be designed, as the dependencies that are important in the team task should be used as a starting point for the development of an observability display. As coordination is the process of managing dependencies in a task, a display that is focused on these dependencies will help a distributed team to coordinate. On the basis of the dependencies of the task, the list of observability elements could be used to select elements for the observability display.

Next to that, present study showed that mainly distributed teamwork on low complexity tasks can be supported with an observability display. It is therefore important to determine the complexity of the tasks a distributed team has to perform. If task complexity is very high, using an observability display might interfere with task performance.

An example of distributed teams that can be supported with an observability display is the urban search and rescue teams, described in the introduction. The time and energy consuming explicit communication that is used within these teams could be (partially) replaced by using observability displays. In this way, the teams would have more time and energy left to work on their main task, excavate victims, as less time and energy is needed for communication and thus coordination.

Goal of present study was to study the effects of team experience and task complexity on the use of an observability display and team coordination. In this way, more insight is gained in how to support team members that work together distributed and encounter barriers caused by this work setting. Present study has shown that coordination within distributed teams improved over time, even though the only used coordination mechanisms were a shared mental model and the observability display. This indicates that the observability display is useful for distributed teams, as it gives team members the possibility to be aware of each others' activities and coordinate tasks without disruptive interruptions. Next to that, the study showed that the use of the observability display and the coordination is influenced by the complexity of a task. As the observability display was used more in the low complexity tasks, this could be used as an indication of which tasks could be supported with an observability display.

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Appendix A – Observability Elements

Behavioral Awareness > Activities	PAST	Presence	*Who was here, and when?*	Gutwin & Greenberg (2002)
		Location	*Where has a person been?*	Gutwin & Greenberg (2002)
		Action	*What has a person been doing?*	Gutwin & Greenberg (2002)
		Action	*How did that operation happen?*	Gutwin & Greenberg (2002)
		Artifact	*How did this artifact come to be in this state?*	Gutwin & Greenberg (2002)
		Event	*When did that event happen?*	Gutwin & Greenberg (2002)
	PRESENT	Presence	*Who is present?*	Gutwin & Greenberg (2002)
		Location	*Where are they working?*	Gutwin & Greenberg (2002)
		Workspace	*What does their workspace look like?*	Gutwin, Roseman, & Greenberg (1996)
		Environment	*How does the work place of the others look like?*	Van der Kleij (2007)
		Task composition	*Composition of task and subtasks*	
		Importance	*How important is the work?*	Bolstad & Endsley (1999)
		Deadlines	*What deadlines do the others have?*	Jang, Steinfield, & Pfaff (2002)
		Progress	*What is the progress of the task?*	
		Action/Task	*What are they doing?*	Gutwin & Greenberg (2002)
		Intention	*What goals is that action part of?*	Gutwin & Greenberg (2002)
		Artifact/Objects	*What object are they working on/using?*	Gutwin & Greenberg (2002)
		Gaze	*Where are they looking?*	Gutwin & Greenberg (2002)
		View/Extents	*Where can they see?*	Gutwin & Greenberg (2002)
		Reach	*Where can they reach?*	Gutwin & Greenberg (2002)
		People	*Whom do they work with?*	Vertegaal & Velichkovsky (1997)
		Physical Acitivty	*How much movement do they make?*	
		Cognitive Activity	*What is the level of cognitive activity of others?*	
		Activity/Workload	*How active are they? How much is demanded from others?*	Eisen & Hendy (1987); Vertegaal & Velichkovsky (1997)
		Stress	*Do the others perceive stress? (Able to handle demands?)*	
		Help	*Do they need help?*	
		Help	*Can they be disturbed?*	Dabbish & Kraut (2008)
		Physical Appearance	*How old are the others?*	Van der Kleij (2007); Zheng et al. (2002)
		Physical Appearance	*How do the others look?*	Van der Kleij (2007); Zheng et al. (2002)
		Multiple team membership	*Are others part of multiple teams at the same time?*	
		Responsible	*Who is responsible for this action/work?*	
		Leadership	*Who has the lead?*	
		Leadership	*Who follows the lead?*	
		Time	*To which degree do others work/operate at different times/shifts?*	Van der Kleij (2007)
		Distance	*What is the average geographical distance between members?*	Van der Kleij (2007)
		Configuration	*What is the number of working sites?*	Van der Kleij (2007)
		Language	*What language do others speak?*	Van der Kleij (2007)
		Novelty	*How novel is the work to others? Prior experience?*	

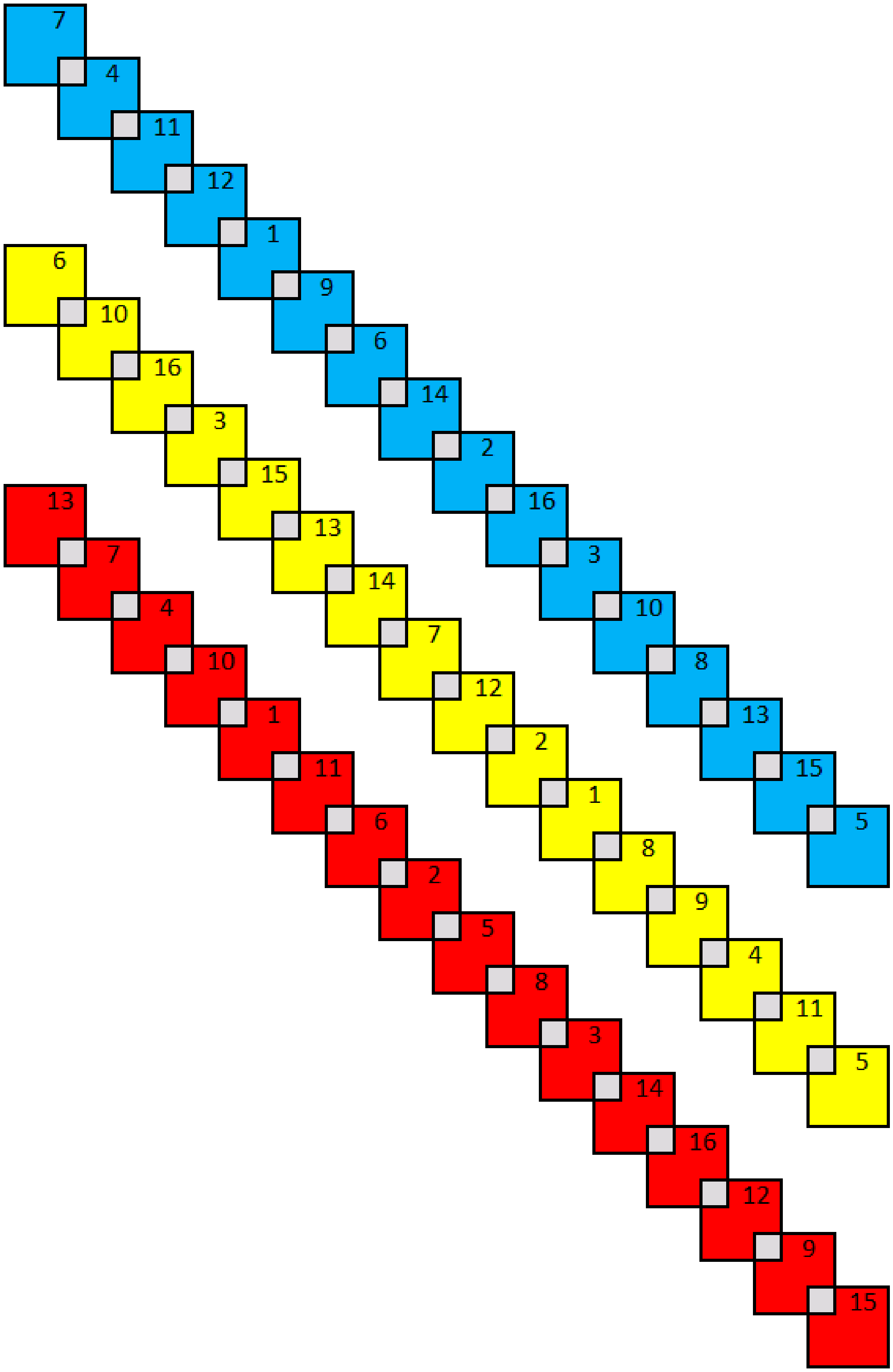
Behavioral Awareness > Activities	PRESENT	Activity (Communication)	*How active are they communicating?*	Vertegaal & Velichkovsky (1997)
		Location (Communication)	*Where are the people they communicate with?*	Vertegaal & Velichkovsky (1997)
		Action (Communication)	*What action are they referring to? (Subject)*	Vertegaal & Velichkovsky (1997)
		Objects (Communication)	*What objects are they referring to?*	Vertegaal & Velichkovsky (1997)
		People (Communication)	*Whom do they communicate with?*	Vertegaal & Velichkovsky (1997)
		Extents (Communication)	*What channels can they use?*	Vertegaal & Velichkovsky (1997)
		Abilities (Communication)	*Whom can they communicate with?*	Vertegaal & Velichkovsky (1997)
	FUTURE	Intention - Action	*What will they do next?*	Vertegaal & Velichkovsky (1997)
		Intention - Need	*What do they need next?*	
		Expectations	*What do they need me to do next?*	Vertegaal & Velichkovsky (1997)
		Intention (Communication)	*Whom will they communicate with next?*	Vertegaal & Velichkovsky (1997)
		Expectations (Communication)	*Who wants to communicate with me next?*	Vertegaal & Velichkovsky (1997)
		Workload	*Do the others have enough spare capacity to cope with emergency situations?*	
Cognitive Awareness >Knowledge of others	PRESENT	Abilities/Skills	*What can they do?*	Vertegaal & Velichkovsky (1997)
		Knowledge	*What do they know? (Knowledge level)*	Dehler, Bodemer, Buder, & Hesse (2011)
		Mood	*What is the mood of the person?*	De Dreu, Baas, & Nijstad (2008)
		Workload	*Do they have capability to perform the required task?*	Eisen & Hendy (1987)
		Way of working	*How do they work normally? What are their working habits*	
	FUTURE	Influence	*Where can they make changes?*	Vertegaal & Velichkovsky (1997)
		Knowledge	*What do they have to know?*	
Social Awareness >Functioning of group as perceived by others		Friendliness (Me)	*How friendly are others?*	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
			How friendly do others think I am?	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
		Cooperative (Me)	*How cooperative are others?*	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
			How cooperative do others think I am?	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
		Reliability (Me)	*How reliable are others?*	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
			How reliable do other think I am?	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
		Influence (Me)	*How much influence do others have?*	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
			How much influence do others think I have?	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
		Productivity - Me	*How productive do others think I am?*	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
		Quality of Contribution - Me	*How do others rate the quality of my contributions?*	Phielix, Prins, Kirschner, Erkens, & Jaspers (2011)
		Trustworthy (Me)	*How trustworthy are others?*	
			How trustworthy do others think I am?	
		Extraversion (Me)	*How extroverted are others?*	
			How extroverted do others think I am?	
		Conscientiousness (Me)	*How conscientiousness are others?*	
			How conscientiousness do others think I am?	
		Stability (Me)	*How stable are others?*	
			How stable do others think I am?	
		Openness to experiences (Me)	*How open to experiences are others?*	
			How open to experiences do others think I am?	

Appendix B Task Information Example – Color combinations

SET	KLEUREN		
1	ROOD	GEEL	GEEL
2	ROOD	ROOD	BLAUW
3	GEEL	GEEL	BLAUW
4	GEEL	BLAUW	BLAUW
5	BLAUW	BLAUW	ROOD
6	ROOD	ROOD	GEEL
7	BLAUW	GEEL	BLAUW
8	ROOD	ROOD	BLAUW
9	ROOD	GEEL	GEEL
10	GEEL	GEEL	BLAUW
11	ROOD	ROOD	GEEL
12	ROOD	BLAUW	ROOD
13	GEEL	GEEL	BLAUW
14	ROOD	BLAUW	BLAUW
15	BLAUW	BLAUW	ROOD
16	ROOD	GEEL	GEEL

Het eerste setje moet dus een rode en twee gele sudoku's bevatten.

Appendix C Task information Examle –Order of Sudoku puzzles



Appendix D – Questionnaires

Questionnaire Situation Awareness

Each trial, participants had to answer five questions concerning the team's activities. Participants never had to answer questions marked with a * about their selves, only about the two other team members.

'What is the color of the puzzle person A is solving now?' *

red / blue / yellow / this person is not solving a puzzle at this moment

'What is the color of the puzzle person A is going to solve after the current puzzle?' *

red / blue / yellow / not indicated

'How many puzzles has person A solved this block until now?' *

....

'How many yellow puzzles has person A solved this block until now?' *

....

'How many puzzles have person A, B and C solved together until now this block?'

....

'How many yellow puzzles have person A, B and C solved together until now this block?'

....

'Who has solved the most puzzles this block until now?'

A / B / C

'Who will solve the most puzzles this block?'

A / B / C

'How long has person A been working on this present puzzle?' *

0-2 minutes / 2-4 minutes / 4-6 minutes / longer than 6 minutes

Questionnaire Task Complexity (7-point Likert-Scale)

‘I found this to be a complex task’

‘This task was mentally demanding’

‘This task required a lot of thought and problem-solving’

Questionnaire Team Related Shared Mental Model (7-point Likert-Scale)

‘Judge the skills of each of the team members, yourself included, on a scale from 1 (very bad) to 7 (very good)’

A	Solving Sudokus
	Coordinating tasks between team members
	Contribute to making color combinations
B	Solving Sudokus
	Coordinating tasks between team members
	Contribute to making color combinations
C	Solving Sudokus
	Coordinating tasks between team members
	Contribute to making color combinations

Questionnaire Intra Team Coordination (7-point Likert-Scale)

‘Activities were well coordinated with other team members’

‘Coordination with other team members went smoothly’

‘Double and overlapping activities were avoided’

‘Conflicts with other team members were settled quickly’

Questionnaire Perceived Usefulness (7-point Likert-Scale)

‘The Observability Display is useful’

‘The Observability Display gives insight to the team process’

‘ The Observability Display keeps me up to date effectively about relevant progress on the task’

Questionnaire Ease of Use (7-point Likert-Scale)

‘The Observability Display is easy to master’

‘The Observability Display is easy to use’

Appendix E – Observability Display