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Deliverable D4

User Experiences with Asymmetric Distributed Collaboration

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Contents

1 Introduction

This is the fourth deliverable for Marie Curie Outgoing International Fellowship project 21743, "Distributed Crisis Management Using Remote Collaboration Technologies". It describes the results of experiments investigating how teams of participants used linked tabletop and handheld displays to co-ordinate their work in several scenarios in a simulated urban environment.

The first deliverable for this project, D1 (Ashdown, 2007), introduced emergency response as the chosen application area. D2 (Ashdown, 2008b) described various technical aspects of the collaborative system developed to address the needs of distributed emergency response teams. D3 (Ashdown, 2008a) is the design of an experiment on participants' use of the system and the difference that it makes to their performance.

This deliverable, D4, describes the results of the primary experiment, and several secondary ones, to evaluate the remote collaboration technology that has been developed, understand how people use it, and suggest improvements. This section describes the experiments, then Section 2 presents the results, Section 3 is a discussion of the results, and Section 4 is a brief conclusion. The appendices contain copies of some of the written materials given to experimental participants, and extra detail on some of the results.

1.1 Experiments

The main experiment that was conducted placed two-person teams in an urban search and rescue (USAR) scenario as described in deliverable D3. One participant took the role of the tactical actor in a command centre, and used a large tabletop display to arrange information and co-ordinate the work of the team. The other participant took the role of a search unit in the field, and used a small handheld display to view information, and a conventional computer to interact with a simulated urban environment. The teams were given USAR missions, where the goal was to search a set of buildings, report their findings, and rescue any victims, as quickly as possible.

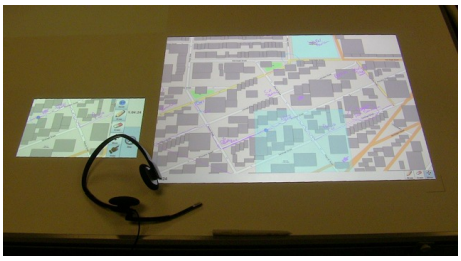
The main experiment is described briefly in Section 1.1.1 below, followed by another USAR experiment with larger teams (Section 1.1.2), a guiding task used for conversation analysis (Section 1.1.3) and use of the system for testing and demonstrations (Section 1.1.4).

1.1.1 Two-person USAR teams

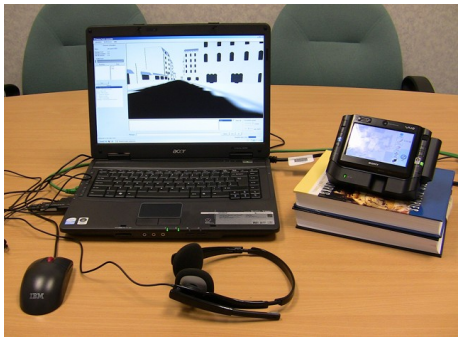
Thirteen pairs of people participated in this experiment. The procedure was as described in deliverable D3, with one person being the tactical actor at the tabletop display (Figure 1(a)), and the other being the search unit at the handheld display (Figure 1(b)). Participants could speak to each other via headsets. They shared several visual workspaces via their displays: a map, a timeline, and reports on sites searched and victims found. The workspaces had various *workspace awareness features* (WAFs) designed to aid synchronous remote collaboration, as described in deliverable D2 (Ashdown, 2008b). The WAFs were telepointers, traces showing a history of telepointer movement, viewports indicating the region of a workspace that another person can see, and continuous feedthrough of map annotation, user interface widgets, and direct manipulation. Also, an *over-the-shoulder view* on the tabletop showed an interactive copy of the handheld display.

The goal of the search unit was to find designated sites in the simulated environment, and accurately report findings once they were searched. Navigation was made more challenging because some roads were blocked, and some were not visibile on the map. The tactical actor scheduled the tasks of the search unit to minimize the time to complete the mission, and aided in navigation. Extra sites, and information, were introduced at fixed times during the mission to cause the team to change their plan. Each pair of participants completed two USAR missions, one with the WAFs disabled and one with them enabled. These two conditions will be referred to as *WithoutWAF* and *WithWAF*.

Various types of data were collected for analysis. Initially the participants completed a survey about themselves and their experience with relevant technology. A video recording was made of the participants' conversation and the contents of the shared workspaces. Figure 2 is an example image from



(a) Tabletop display.



(b) Simulated environment and handheld device.

(c) Person using tabletop.

(d) Person using handheld.

Figure 1: Hardware used by experimental participants. Both used headsets for voice communication. The handheld user viewed a simulated 3D environment on a laptop computer.

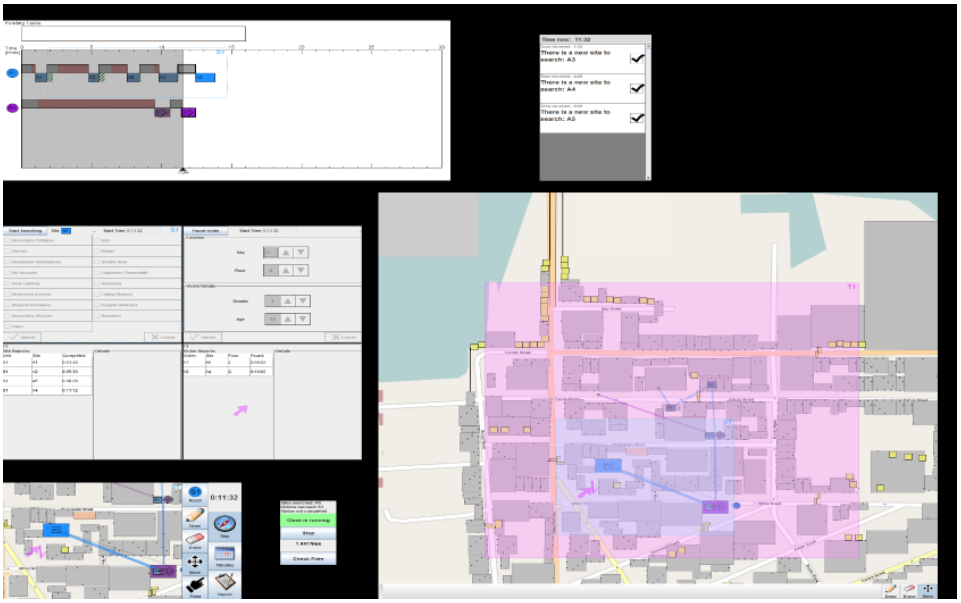


Figure 2: Image from the video containing the shared workspaces used by the two-person USAR team participants. The video captures views of the shared map (bottom right), timeline (top left), and reports (middle left), and the 'over-the-shoulder view' of the handheld display (bottom left).

this video. The recorded display was specifically arranged to aid later analysis, and was somewhat different from the displays used by the participants. After each of two USAR missions, the participants completed a questionnaire about the mission. They completed a final questionnaire on their preference between the two conditions (WithoutWAF and WithWAF). Finally, there was a retrospective review where participants watched the videos of their missions and were asked about techniques they used and decisions they made, to elicit feedback and suggestions.

1.1.2 Three-person USAR teams

In the two-person USAR experiment the tactical actor has just one human subordinate in the form of a search unit, plus a simulated rescue unit. An actual emergency response organization will have a span of control of up to seven, as specified by the incident command system (Bigley & Roberts, 2001). To test how the remote collaboration technology could scale up, an experiment was conducted with three-person teams: one tactical actor, two search units, and a simulated rescue unit. Two teams of three people participated in this experiment.

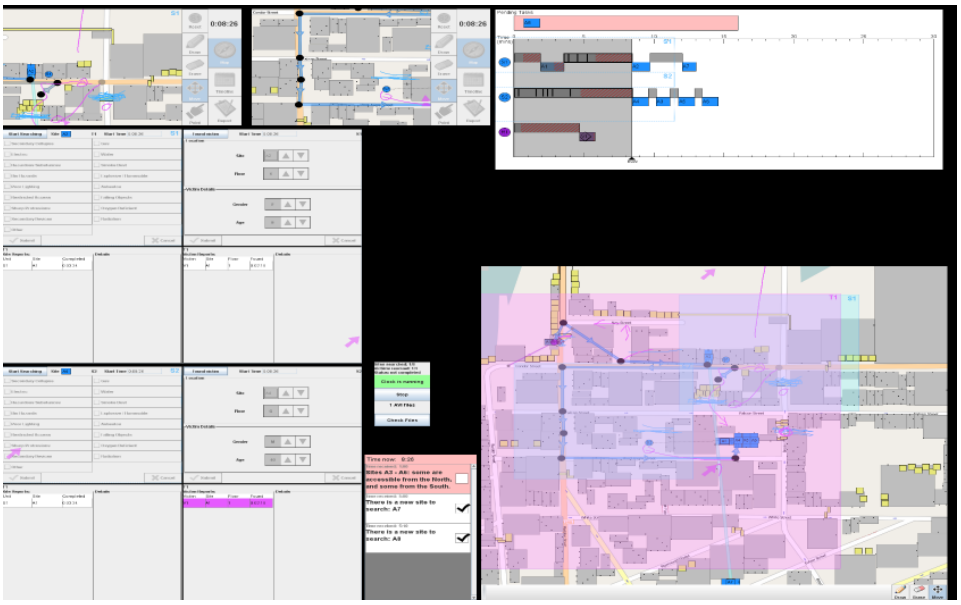


Figure 3: An image from a video containing the shared workspaces used by the three-person USAR team participants. This is like Figure 2, but there is more information to show now because there are two search units rather than one.

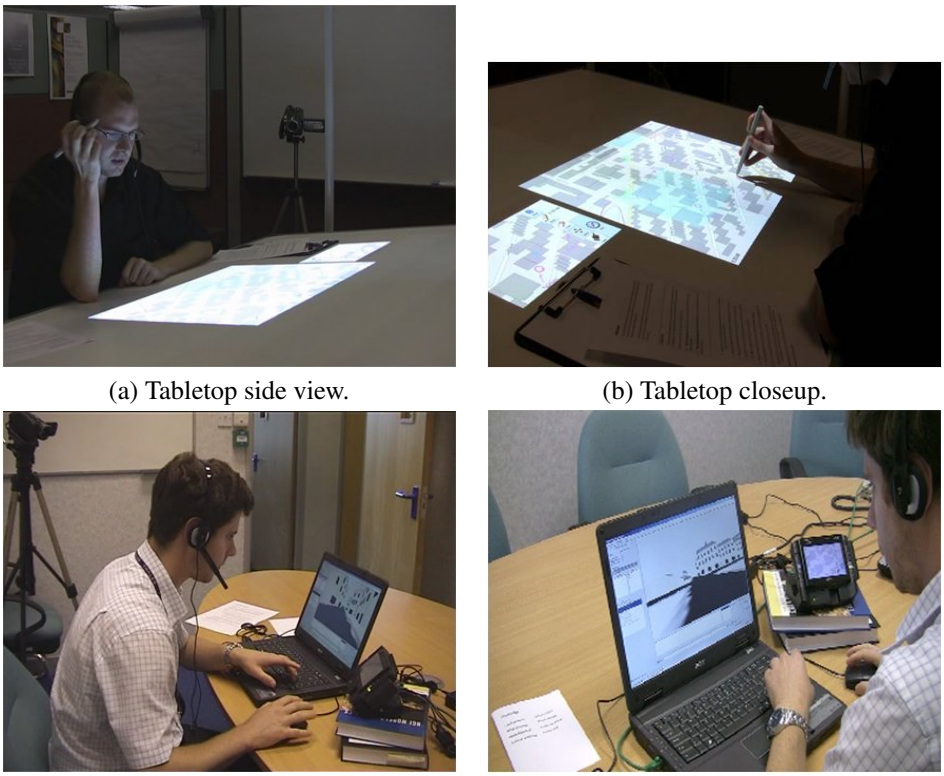
Each team completed two missions, one in condition WithoutWAF and one in condition WithWAF. The USAR missions were similar to the ones in the two-person experiment, and were designed to have a similar level of difficultly. The number of sites to search and victims to rescue in each of the experiments was as follows.

- Two-person teams (one search unit)
  - Mission 1: 4 sites, 3 victims
  - Mission 2: 5 sites, 3 victims
- Three-person teams (two search units)
  - Mission 1: 8 sites, 4 victims
  - Mission 2: 8 sites, 4 victims

A video recording was made of the participants conversation and shared workspaces. The image from the video in Figure 3 shows that there is more information to show than for the two-person teams because there are now two sets of reports and two over-the-shoulder views. The questionnaires for this version of the experiment were modified slightly from the two-person experiment, and are included in Appendix A.

1.1.3 Two-person guiding task

In addition to the experiments based on USAR scenarios described above, an experiment was also conducted where one person guides another around an urban environment to observe and record various security threats that are visible in the simulated environment. Three pairs of people participated. In each pair, one person was at the tabletop and had a textual description of a route to be checked. The other used the handheld device, and navigated around the simulated environment.



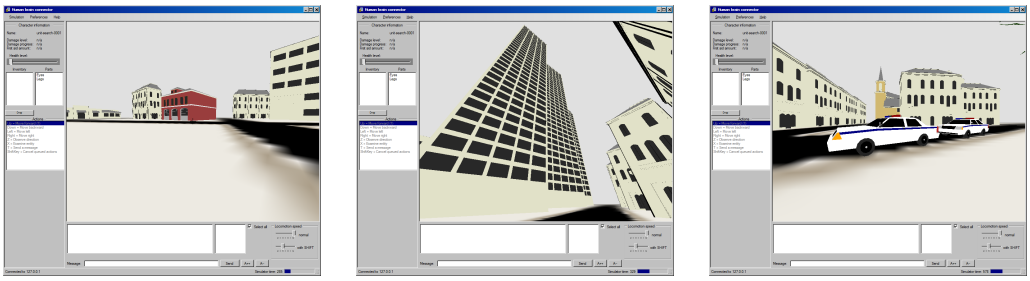
(a) Tabletop side view. (b) Tabletop closeup.

(c) Handheld side view. (d) Handheld closeup.

Figure 4: Four camera views captured for conversational analysis of the two-person guiding task.

This experiment was conducted in collaboration with Professor Paul Luff and PhD student Menisha Patel of the Work Interaction and Technology Group[1] at King's College London. Their speciality is to perform conversation analysis on video of people interacting with each other in naturalistic settings. Conversation analysis is the study of how people talk to each other, using both verbal and non-verbal communication. It is a qualitative data-driven approach that attempts to describe the

[1] http://www.kcl.ac.uk/schools/sspp/mgmt/research/wit/



(a) Landmark to visit: fire station (b) Threat to avoid: tall buildings (c) Positive sighting: police cars

Figure 5: Views of the simulated environment used in the guiding task.

Figure 6: Image from video containing the shared workspace. This is like Figure 2, but is simpler because the only shared workspace is the map.

orderliness, structure, and sequential patterns of interaction.

In this case, the scenario was that a politician was due to visit the city, and the participants' task was to check a route for security threats. The tabletop user had a textual description of the route, and the handheld user had access to the simulated environment, and could see the various security threats. The instructions that were given to participants are in Appendix B.

Two video cameras were used for each participant to capture a full view showing the person's body, and a close-up view showing their interaction with the technology. Figure 4 shows the four views. Figure 5 shows some examples of what the simulated environment looked like. A video of the shared workspace and participants' voices was captured (Figure 6) as in the USAR experiments.

The pairs of participants were introduced to the technology, and had the scenario explained to them. They then read the written instructions. They were given 30 minutes to complete the task of walking the route and assessing the security threats. At the end they completed the questionnaire in Appendix B The data collected from this experiment were the five videos (Figures 4 and 6) and the questionnaire responses.

1.1.4 General use of the system

During implementation of the asymmetric collaboration system developed for this project, testing revealed various issues. Also, the system has been demonstrated to various visitors to the two host organizations for this project, the Massachusetts Institute of Technology and Thales Research and Technology UK, and various observations have been made during those demonstrations. In the USAR scenarios, the teams of participants were given a 15-minute introduction to the system, they tried out the features for around 10 minutes, and performed two practice missions, one before each of the actual missions whose results were recorded. These activities were not monitored precisely to give statistical results such as those in the results section below (Section 2), but they did lead to various observations that are included in the discussion (Section 3).

2 Results

Thirteen pairs of people participated in the two-person USAR experiment (26 people in total), 22 men and 4 women. The participants' ages ranged from below 20 to above 59. The mean time to complete a mission was 17.8 minutes (standard deviation = 4.5). Participants completed missions in two conditions: with the workspace awareness features of the shared workspaces disabled (WithoutWAF) and with them enabled (WithWAF). There was no significant effect of the condition on the time for completion.

The results of the two-person experiment are presented below in Sections 2.1 to 2.5, followed by some results from the other experiments.

2.1 Preference for the workspace awareness features

Figure 7 shows the preference of the participants for the shared workspaces in the two conditions. There was a significant preference for the versions of the map and reports with the workspace awareness features, and for the overall system with the features enabled.

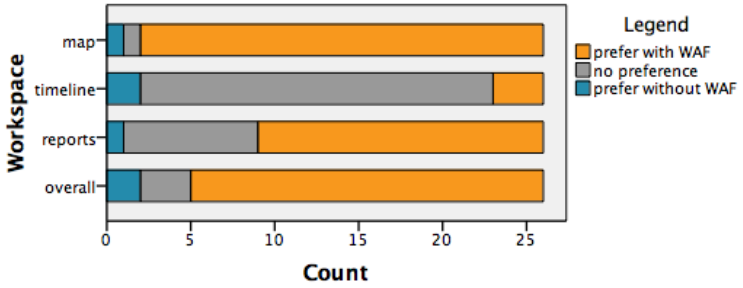


Figure 7: Preference of the 26 participants for the workspace awareness features, in the three shared workspaces (map, timeline, and reports) and overall.

2.2 Questionnaire responses

Figure 8 shows the responses of the participants to the multiple-choice post-mission questions. The questionnaire was the same for the two conditions, WithoutWAF and WithWAF, but questions 16 to 20 were only relevant to the WithWAF condition.

There were no statistically significant differences between the two conditions. Generally participants were pleased with their team's performance (Q1–2), and they found the workload to be moderate (Q3–6). They found the ability to speak to each other and share information, and using, sharing, and annotating the map to be very useful (Q7–12). The reports were somewhat less useful for collaboration (Q15), and participants were rather ambivalent about the timeline (Q13-14). They mostly found the workspace awareness features quite useful (Q16–20).

Q1. My team was successful in accomplishing its mission.

Q2. The members of my team worked together effectively.

Q3. I found the task mentally demanding.

Q4. I found the pace of the task to be fast.

Q5. I had to work hard to accomplish the mission.

Q6. I became frustrated during the mission.

Q7. The workspaces we used (map, timeline, and reports) helped us achieve our goal.

Q8. The ability to speak to each other was useful.

Q9. The ability to share visual information with each other was useful.

Q10. The map provided useful information for me.

Q11. The map was useful for collaboration with the other team members.

Q12. The ability to annotate the map was useful.

Q13. The timeline provided useful information for me.

Q14. The timeline was useful for collaboration with the other team members.

Q15. The site and victim reports were useful for collaboration with the other team members.

Q16. The over-the-shoulder view (copy of the handheld display on the tabletop) was useful for collaboration.

Q17. The telepointers were useful for collaboration.

Q18. The traces were useful for collaboration.

Q19. The visibility regions were useful for collaboration.

Q20. The highlighting of symbols was useful for collaboration.

Q21. The highlighting of symbols was useful for me individually.

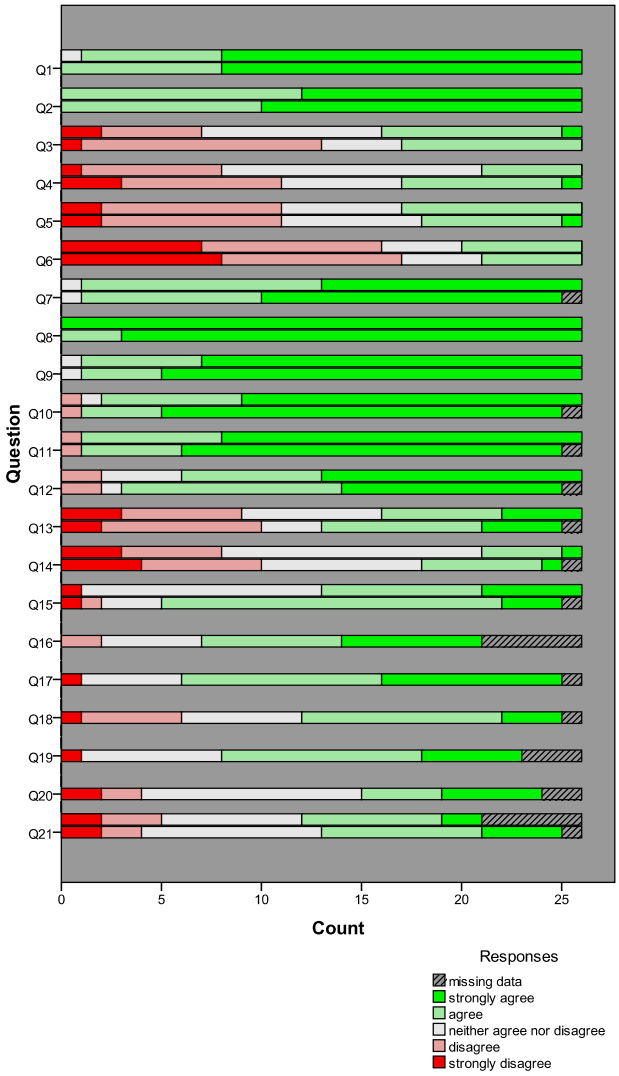


Figure 8: Likert scale responses for the 21 questions in the post-mission questionnaire. The upper bar in each pair is for the condition without workspace awareness features, and the lower bar is the condition with them. Questions 16 to 20 were only applicable to condition WithWAF.

2.3 Communication efficiency

Following Diamant et al. (Diamant, Fussell, & Lo, 2009), a set of categories for the utterances of the participants was identified. This was done inductively until a set of categories that could code the full range of utterances was obtained.

The categories of utterance are: *status* (querying or declaring a participant's actions), *guiding* (tactical actor helping the search unit to navigate around the simulated environment), *situation awareness* (querying or describing the state of the world), *report* (voicing information for the other participant to enter into a form), *feedback* (acknowledging a previous utterance), *social* (chat and joking), *meta-coordination* (discussion about the experiment or technology), and *other* (uncodable or unintelligible utterances).

Guiding and situation awareness utterances have subcategories of *deictic* and *non-deictic* to indicate whether the participant making the utterance pointed to the map. For example, the command "Take Putnam Street" uses the name of a street and so does not require any further clarification. The command "Go this way" requires a gesture to complete the utterance, and so is deictic. With workspace awareness features enabled, participants could make deictic gestures with the telepointers and annotations, and possibly by moving the visibility region. With them disabled, only the annotations were available for making deictic utterances. Table 1 lists the utterance categories.

Utterance type	**Sub-type**	**Examples**
Status		(The speaker informs of an action he is doing or report he is completing) T: "Have you started searching yet?" S: "I've entered site A1 now" S: "I've found a victim" S: "Submit"
Guide	Deictic	T: "Go this way" S: "This way?" T: "No, that way"
	Non-deictic	T: "You should go down Putnam Street" T: "I think you've gone too far"
Situation awareness	Deictic	S: "There's a road block here"
	Non-deictic	T: "Can you see any road blocks ahead?" S: "There's a road block in front of me" T: "I've sent the rescue team" S: "There's one floor, four rooms" S: "Which site is this?"
Report		(The speaker conveys information for the listener to enter into a site or victim report) S: "Sharp protrusions are present" S: "The victim is on the ground floor" S: "I've found a victim" S: "I've entered site A1 now" S: "Submit"
Feedback		"Ok", "yes", "no", "that's good"
Social		*laugh*
Meta-coordination		T: "How do I move the map?" T: "Can you see my route?"
Other		Uncodable or unintelligible utterances

Table 1: Utterance categories found in participants' speech. T denotes the tactical actor (tabletop), and S the search unit (handheld).

For each utterance we recorded three pieces of information:

- Person who spoke (tactical actor or search unit)
- Number of words

- Category of utterance

Figure 9 shows the distribution of utterance types for the two conditions. Most words are spent on status and guiding, with fewer on situation awareness, reporting, feedback, and meta-coordination, and very few that were social or uncategorizable. The only significant difference between the two conditions, was that there was more deictic guiding in condition WithWAF ($t(12)=4.370$, $p=0.001$). The total amount of guiding was roughly equal between the two conditions. Detailed results are given in Appendix D. Deictic guiding in condition WithWAF could use the workspace awareness features, and in particular the telepointers. In the other condition it was restricted to using the annotations.

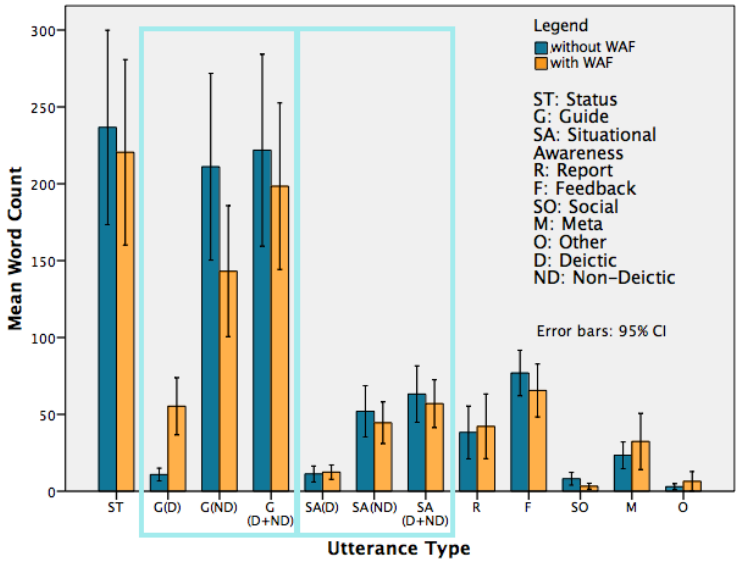


Figure 9: Word counts for the different types of utterances. The deictic (D) and non-deictic (ND) counts are shown separately, and summed (D+ND).

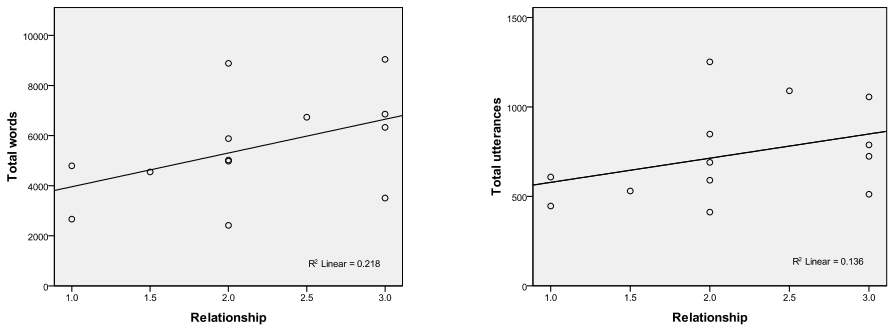
Voicing the start and end of the search of each site was almost universal. This was done for all site searches in 22 of the 26 missions, and for most of them in a further two missions. Only one team did not voice the transitions in this way, and this was a team where the participants had never met before. This may have been because in that team the participants did not know each other at all so S was reluctant to speak much. The start and end of the search reports marked transitions between the two main tasks of the search unit, searching and moving, so these were natural points for the searcher to update the tactical actor on his status. These tasks and the transitions between them were identified in the original cognitive task analysis in deliverable D1 (Ashdown, 2007, page 25).

Observationally, it seemed as if people who knew each other better, spoke more. Questions 10 and 11 in the pre-study questionnaire (Ashdown, 2008a) measured how well people knew each other. Each person rated how well they knew the other one on a three-point scale:

1. I don't know him/her.
2. we are acquaintances but I don't know him/her well.
3. I know him/her well.

The strength of a relationship was deemed to be the average of the two scores from the above list (which were not always the same for the two people in a pair). The amount of conversation was measured simply as the total number of words spoken.

Figure 10 shows the interaction between strength of relationship and amount of conversation. The linear correlation is not statistically significant, but the graphs do suggest more conversation within teams that were more familiar with each other.



(a) (b)

Figure 10: Amount of conversation between pairs of participants in (a) words and (b) utterances, against the strength of their relationship. The correlation is not statistically significant.

2.4 Workload

After the USAR missions the participants were asked to assess their subjective workload by some of the questions in the questionnaire. Four questions, based on questions from NASA TLX (task load index), measured mental demand, temporal demand, effort, and frustration. Figure 11 shows the results of those questions for the two conditions, when treated as interval values and averaged. There was no significant difference in workload between the two conditions. Physical demand was omitted from the questions because it was not relevant to this experiment.

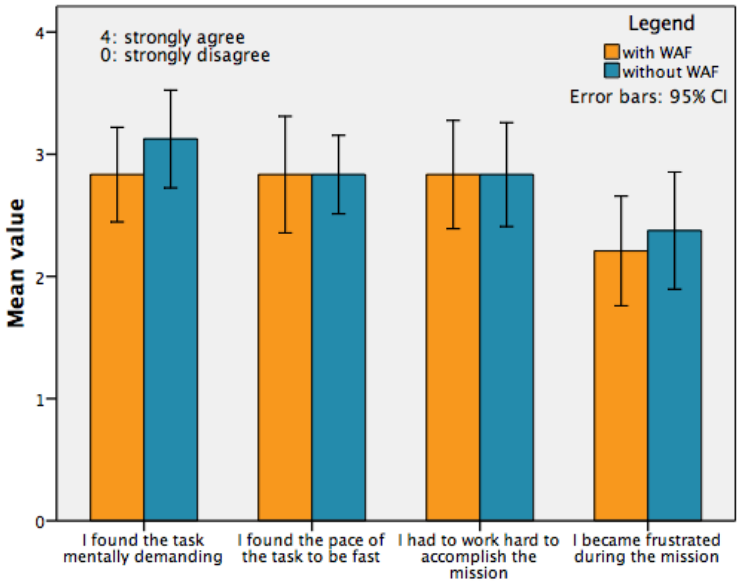


Figure 11: Subjective workload. The questionnaire responses on a five-point Likert scale have been treated as interval values. The means and 95% confidence intervals are shown.

2.5 Strategies

The videos of the 26 experimental missions were reviewed to identify strategies that the participants used. The strategies that were used for entering reports and giving directions are described below.

2.5.1 Entering reports

In the experiment, reports had to be completed as part of the urban search and rescue scenario. There were two types of report: site reports indicating hazards found at a site, and victim reports indicating the location and description of a victim to be rescued. Either participant (tactical or search unit) could enter a report, but it was the search unit that was given the information. In condition WithWAF the participants could work on a report simultaneously, whereas in condition WithoutWAF the report had to be entered by one person or the other.

Figure 12 shows the proportion of reports entered by each of the participants in the two-person teams. This was determined from the program logs. The figure shows that there is a roughly equal split between reports entered by the search unit, and ones entered by the tactical actor. In condition WithWAF a small number of reports were entered by both S and T: part of the report by one and part of it by the other. This simultaneous access to a report was not possible in the WithoutWAF condition.

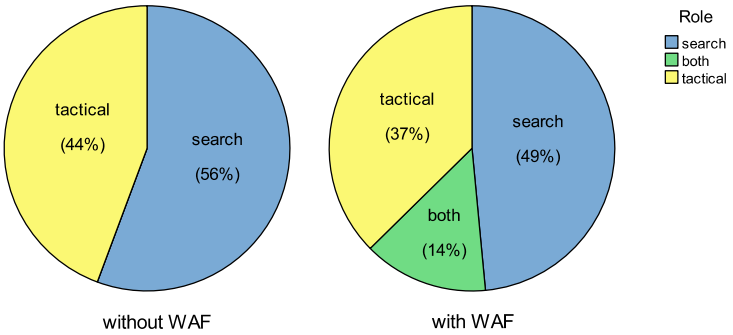


Figure 12: How report completion was shared between the two participants.

Following Gutwin and Greenberg (Gutwin & Greenberg, 1999), the strategies the participants used to complete reports were identified by watching the recordings of the experiment sessions. Table 2 lists the strategies that were found. Some of the strategies were only available in the condition with the workspace awareness features (condition WithWAF).

Strategy	**Available in WithoutWAF**	**Description**
Silent	Yes	S silently enters and submits the report.
Voice-transition	Yes	S enters the report, and indicates the start and finish vocally to T.
Voice-content	Yes	S enters the report, and voices the contents as he enters them.
Delegate-voice	Yes	S voices the results. T enters them and vocally acknowledges or repeats each item.
Delegate-visual	No	S voices the results, T enters them, S watches them being entered on the shared report and acknowledges vocally.
Simultaneous	No	S voices the results, S and T enter them together watching the telepointers and feedthrough to co-ordinate their actions.

Table 2: Strategies used for entering reports. S denotes the search unit and T the tactical actor.

The following is a transcript of delegate-voice, for a site report:

```
S: ... smoke dust is present, and asbestos is present.
T: Smoke dust (T selects 'smoke/dust'), and,
   asbestos (T selects 'asbestos').
S: Yeah.
T: Right, I've got that. (T submits report)
```

The following is a transcript of delegate-visual, for a victim report:

```
S: I have found a victim on the ground floor.
   Gender female, age sixty eight.
T: (Enters details on report)
S: Yeah, that's it.
T: (Submits report)
```

A large majority of cases used one of three categories: voice-transition and voice-content (report entered solely by search unit), and delegate-voice (report entered solely by tactical actor). The silent strategy was rare, presumably because the searcher felt that at least the start and end of searching, and finding a victim, should be indicated vocally. Simultaneous entry may have been avoided because of potential errors due to concurrent input. Delegate-visual may have been less popular because participants were not experienced enough with the technology to exploit it to the full, so they instead relied on a strategy that would have worked without the workspace awareness features.

Strategy	**Available in WithoutWAF**	**Description**
Deictic-telepointer	No	Point with the telepointer. Directions can be indicated by moving the telepointer back and fore, causing the trace to make a line.
Deictic-annotation	Yes	Draw on the map, for instance, using a circle to show a point, or a line or arrow to show a route. The annotation may be erased as soon as it has served it's purpose.
Deictic-waypoints	Yes	Place the waypoints and refer to them explicitly e.g., "Follow the blue arrow."
Actor-location	Yes	Relative to operational actor's physical location e.g., S says "There is a blockage where I am now".
Actor-direction	Yes	Relative to operational actor's direction, for example, T says "Turn left"
Actor-historical	Yes	Relative to operational actor's previous movement e.g., "Turn around. Go back the way you came."
Map-direction	Yes	Directions aligned to map: up, down, left, right.
Map-view-location	No	Relative to one user's view of the map, for example, "in the bottom left of the map". This is only practical if the speaker knows what part of the map the listener has visible.
Map-view-movement	No	Someone moves S's view, and uses the visibility rectangle to demonstrate a location or direction.
World-direction	Yes	Directions aligned to the world: north, south, east, west.
World-landmark	Yes	Use a description of a world object e.g., "Continue until the five-way crossroads."
World-name	Yes	Use the proper name of a world object e.g., "Walk along Condor Street."

Table 3: Strategies used for specifying locations and directions. S denotes the search unit and T the tactical actor.

2.5.2 Giving directions

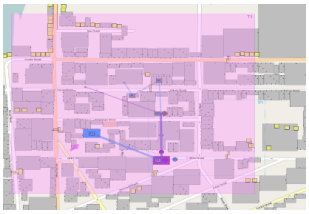
Participants in the USAR scenario had to find their way around an urban environment, and to make it more realistic and challenging, the map they were given did not correspond exactly to the simulated environment. Some roads were blocked, and there were some alleys that were not shown on the map. Also, the tactical actor was given extra information, such as a particular building being accessible only from the south side, so the two participants had to collaborate. Navigating around the simulated environment using this information was major part of the activities of the participants.

The map on the handheld device had to be panned many times, because the small screen was only large enough to show a small part of it at one time. In condition WithoutWAF this panning had to be done by the search unit (S). However, in condition WithWAF, the panning could either be done by S, by both S and T, or just by T. The actual distribution among the 13 teams was:

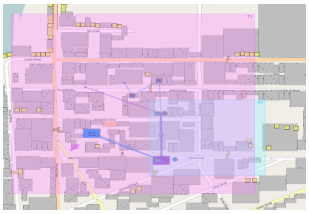
- In 7 teams, only S panned the map.
- In 4 teams, S and T both panned the map.
- In 2 teams, only T panned the map, on behalf of S.

The participants used various strategies for collaborative navigation. Some of these just used the voice channel, and others used voice and gestures. Table 3 lists the strategies that were used.

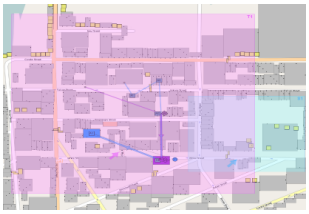
The map-view-movement was an unexpected strategy, which uses not just the location, but the movement of the visibility region to indicate a direction. It is illustrated in Figure 13.



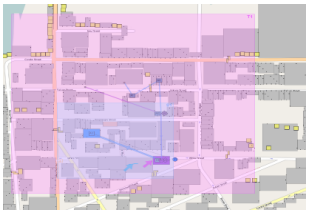
(a) S's region is not visible.



(b) S switches to map. Region (blue box) becomes visible.



(c) S pans to the right.



(d) S pans to the left.

```
S: (a) OK, I'm out (b)
T: You're out. So if you carry along ... White Street
S: This direction? (c)
T: Um, no other [way
S:              [or, this [direction (d)
T:                        [yep, yep, that way
T:  And [you'll see A [3.
S:      [OK           [oh A3.
```

Figure 13: Transcript of an example of the map-view-movement strategy for gesturing on the map. The "[" symbol indicates words spoken simultaneously.

2.6 Three-person teams

Two teams participated in the three-person USAR experiment (six people in total). They completed questionnaires after each of their two missions, and a preference questionnaire at the end. These

questionnaires were modified slightly from the first experiment, and are included in Appendix A. In this case, participants preferred to have the workspace awareness features on the map, but indicated no preference for the timeline and reports (Figure 14). This is different from the two-person USAR experiment, where the extra features were preferred on the reports (Figure 7 on page 8).

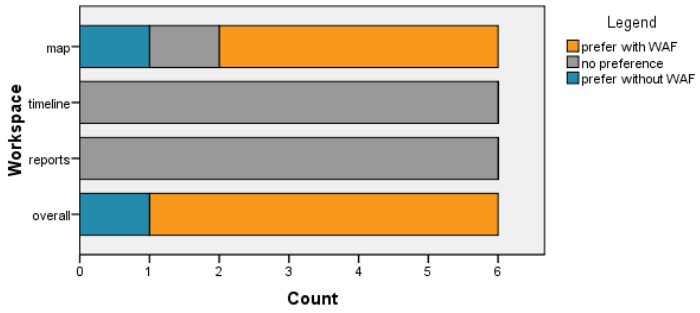


Figure 14: Preference for the workspace awareness features from the three-person team members. Compare with Figure 7 on page 8.

Figure 15 shows the Likert-scale questionnaire responses from the participants, for comparison with the responses from the two-person teams. The questions were same in both cases. The responses were much the same, although participants were less enthusiastic about the use of the timeline and reports for collaboration (questions 14 and 15).

Another difference in the three-person case was the observation that status reports were more brief. For example, this is a transcript from the first three-person team, where the second search unit is reporting the find of a victim.

```
(S2 completes a victim report)
S2: Victim
T: OK
```

Table 4 lists the frequencies of strategies used for entering reports. Almost all site report entries used a combination of the silent and voice-transition strategies. The single use of delegate-voice was due to a bug in the handheld user interface: a search unit could not enter his own report, so the tactical actor did it for him. All victim report entries used the silent or voice-transition strategy. In the two-person teams about half of the report completion was performed by the tactical actor, as shown in Figure 12, but in the three-person teams it was all done by the search units, except for the single instance of delegate-voice. This seems to explain why the WAFs were not preferred for the reports, although they were in the two-person experiment: in the three-person case the search units decided to perform all of the report completion themselves rather than doing it collaboratively.

Strategy	Site reports	Victim reports
Silent and voice-transition	28	16
Voice-content	3	0
Delegate-voice	1	0
Delegate-visual	0	0
Simultaneous	0	0

Table 4: Strategies from Table 2 used for entering reports in the three-person teams.

Generally, because of the contention for the voice channel, speech tended to be more terse when there were three people in the team. The utterances of the participants were not categorized and counted, as in the two-person experiment, because of the small number of participants.

Q1. My team was successful in accomplishing its mission.

Q2. The members of my team worked together effectively.

Q3. I found the task mentally demanding.

Q4. I found the pace of the task to be fast.

Q5. I had to work hard to accomplish the mission.

Q6. I became frustrated during the mission.

Q7. The workspaces we used (map, timeline, and reports) helped us achieve our goal.

Q8. The ability to speak to each other was useful.

Q9. The ability to share visual information with each other was useful.

Q10. The map provided useful information for me.

Q11. The map was useful for collaboration with the other team members.

Q12. The ability to annotate the map was useful.

Q13. The timeline provided useful information for me.

Q14. The timeline was useful for collaboration with the other team members.

Q15. The site and victim reports were useful for collaboration with the other team members.

Q16. The over-the-shoulder view (copy of the handheld display on the tabletop) was useful for collaboration.

Q17. The telepointers were useful for collaboration.

Q18. The traces were useful for collaboration.

Q19. The visibility regions were useful for collaboration.

Q20. The highlighting of symbols was useful for collaboration.

Q21. The highlighting of symbols was useful for me individually.

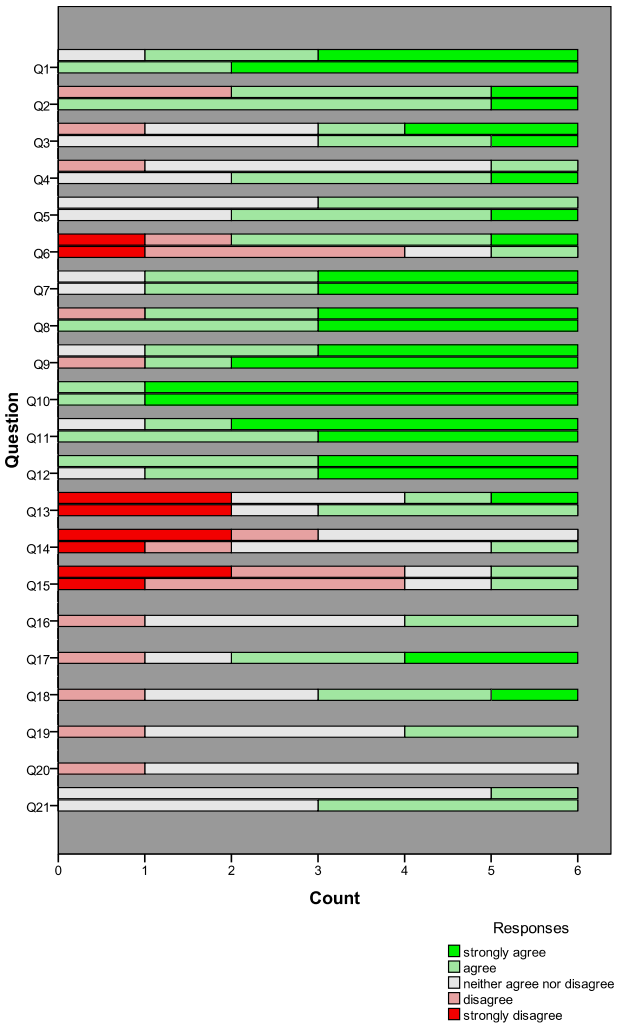


Figure 15: Likert scale responses for the 21 questions in the post-mission questionnaire for three-person teams. The questions are the same as those given to the two-person teams. The upper bar in each pair is for the condition without workspace awareness features, and the lower bar is the condition with them. Questions 16 to 20 were only applicable to the condition with the WAFs. Compare with Figure 8 on page 9.

2.7 Guiding task

Participants in the guiding tasks were given a questionnaire at the end of the task, and the videos of the session were used for conversation analysis. The results of the questionnaire are shown below, and the conversation analysis is included later (Section 3).

2.7.1 Questionnaire responses

Figure 16 shows the responses to the Likert-scale questions. There were not enough participants to obtain statistically significant results, but the usefulness of the collaborative features seems to be the same as the order in which they are listed: annotations were most useful (Question 5), then telepointers, visibility regions, and finally the over-the-shoulder view about which the participants were rather ambivalent (Question 8).

Q1. The ability to speak to each other was useful.

Q2. The ability to share visual information with each other was useful.

Q3. Seeing the operational unit's location (blue circle on the map) was useful.

Q4. Having the shared interactive map is an improvement over simply showing the blue circle on everyone's map.

Q5. The ability to annotate the map was useful.

Q6. The telepointers (for pointing at the map) were useful.

Q7. The visibility regions were useful.

Q8. The over-the-shoulder view (copy of the handheld display on the tabletop) was useful.

Q9. The use of a tabletop display, instead of a conventional PC, was helpful for this task.

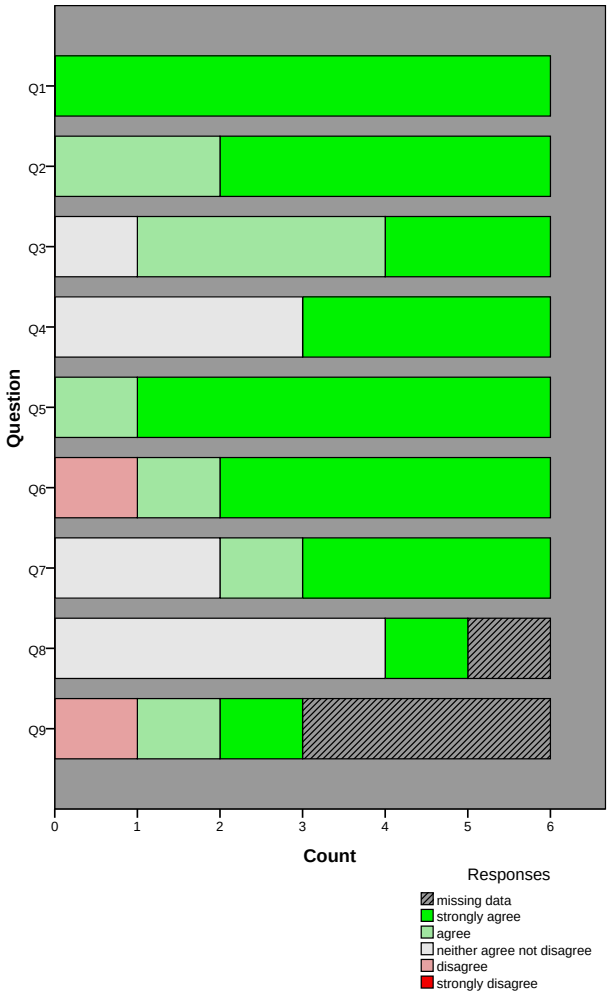


Figure 16: Likert scale responses for the nine questions in the questionnaire for the guiding task. There were six participants.

3 Discussion

Various observations were made of the participants behaviour during the experiments, and afterwards while reviewing the videos. These are described below in Section 3.1. Responses from the participants to the open-ended parts of the questionnaires (Appendix C) have been divided into two parts: feedback on the existing system (Section 3.2), and suggestions for changes (Section 3.3). Section 3.4 describes the differences when three-person teams were used. Section 3.5 is an example result from the conversation analysis of the guiding task.

3.1 Observations

The following points are observations made by the experimenter during the two-person USAR experiment. They were obtained from observation during the experiment, the retrospective reviews with the participants at the end of each experiment, and viewing the videos afterwards.

Different styles of sketching should be supported

Waypoints on the map were added with a circle gesture. Participants were shown how to perform the gesture, and all did so successfully before starting the missions. However, once the mission was underway, many of them reverted to using their instinctive method of drawing a waypoint, which often did not work as well. There were a surprising number of ways that people drew a simple circle. Some of them are shown in Figure 17. They also tended to forget the way they were shown to delete waypoints, by scribbling over them. Care should be taken to make a sketch input system that matches users' intuitive sketches, and allows for various forms of each symbol, or else a sketch system should not be used. Time pressure exacerbates problems with the sketching, because users tend to repeat their existing behaviour when there is a failure to recognize a symbol rather than taking the time to think about why the problem has happened.

Figure 17: Various ways that participants chose to draw a circle.

Drawing is difficult on handheld

The handheld device was small, and the user's finger relatively large. The problems of occlusion of the display and lack of precision of the finger make sketching on the handheld difficult. This is known as the 'fat finger problem'. Handheld users rarely tried to annotate the map with anything more complex than a straight line. If they needed a more specific annotation, they would gesture while talking to the tactical actor, and wait for him to annotate the map in more detail. A stylus could be provided for the handheld device, but this would be more suitable for a larger device used in a less mobile way. At least for the map, drag and drop icons could cater for many of the instances when detailed annotation would otherwise be necessary.

Handedness is an issue

The handedness of the user is a factor to consider, and may need to be used as a variable that modifies the user interface. In the experiment, instructions were presented on the tabletop in a web browser with a scroll bar on the right-hand side. This was fine for right-handed users, but left handed users had to reach across the display, which was awkward, and obscured information as described in Section 3.5. Interfaces could be designed to be handedness-neutral. For example, scrolling performed by dragging the background of the instructions could have been done equally well on either side. The toolbar buttons on the map were on the right, but they could have been in the middle, to even-out the difference between the two hands.

Switching between touch and conventional input was disorienting

Participants in the search unit role had to frequently switch between using the handheld device with touch input, and the PC with conventional keyboard and mouse for the simulated environment. Many people tried to touch the screen of the PC after using the handheld, and then realized their mistake, and reached for the mouse. This shows how people can quickly get used to a particular mode of interaction. Of course, this particular behaviour would not be a problem in real-world use because the handheld user is not using another computer, but interacting with a real environment.

Tactical usually warned before moving visibility region.

In about half of the 13 teams, the tactical actor panned the handheld map remotely. Usually, before he did so, he vocally announced his intention to do so. This is a social protocol that emerged naturally, and indicates that the tactical actor felt he was encroaching into the handheld user's territory.

Experience with games

The search unit in the USAR missions moved around a simulated 3D environment using the mouse and keyboard. The interface to this environment is much like that of the many so-called 'first person shooter' games. Experience with such games was fairly evenly spread among the participants playing the search unit (Table 5). It was obvious from the beginning, which participants had extensive experience with such games, and which of them had none. The initial position of their hands was a giveaway. Experienced gamers would automatically place their two hands simultaneously on the mouse and keyboard controls, but those with no experience would initially try to switch a single hand between the mouse and keyboard. Competence with the 3D environment led to changes in the strategy adopted by the team. Search units comfortable with the 3D environment navigated around quite autonomously, and would suggest alternative routes where applicable. Those who were not comfortable with it required must more guiding from the tactical actor, and would rely on what he said. This is an issue for the design of an experiment like this, because the gaming experience of participants is a significant, probably unwanted, factor affecting the strategy of the team. Future experiments using a similar approach to simulating a mission may be improved by controlling for this variable when selecting participants.

	never	a few times	$<$1 per week	$\geq$1 per week
How many times have you played first person 3D games (e.g., Grand Theft Auto, Doom, Halo)?	5	4	4	0
How many times have you played multiplayer online games (e.g., World of Warcraft or Second Life)?	7	5	1	0

Table 5: Experience with computer games of the 13 participants in the search unit role. The third and fourth responses were actually "many times, but less than once a week now", and "many times, and more than once a week now".

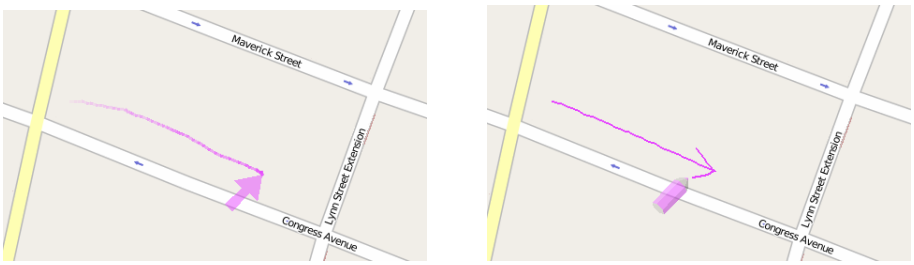
3.2 Feedback

This section contains feedback on the existing collaboration system from the participants of the two-person USAR experiment. The title of each issue is followed by the number of participants who mentioned it in their questionnaire. Thirteen pairs of people participated, so the maximum number of responses was 13 or 26 depending on whether a feature is relevant to one or both of the roles.

On the map, it is not obvious which tool is selected (1)

Modes and buttons on pen are confusing (1)

On a large tabletop display, a toolbar can be far away from the user's focus of attention. It may be out of his field of view, or obscured by arms or hands. Although only two participants explicitly wrote about this, it was apparent from the video that various others suffered from mode confusion. The telepointer attached to the pen indicated the current mode (draw, erase, or pan map) but this was not enough.



(a) (b)

Figure 18: Traces were confused with annotations. (a) The trace faded over time, and showed an arrow for the pointer. (b) The annotation was persistent, and showed a pencil for the pointer.

Trace confused with annotation (3)

The tabletop user could annotate the map using the pen. Also, a telepointer and trace were displayed at the pen location to allow gesturing to the remote user. The trace showed a fading one-second history of the telepointer location, to allow more expressive gesturing, including lines and areas. In many cases the tactical actor did wiggle the telepointer back and fore to show a direction, or trace along some roads to show a route. The problem was that the tabletop user often confused his own trace with an annotation, because they looked very similar (Figure 18). Traces have been shown to improve the interpretation of gestures in the presence of network jitter (Gutwin & Penner, 2002), but there was no significant jitter here—the network conditions were set up to be ideal, to prevent them being a factor. The traces should be redesigned with differentiation from annotations in mind, and the choice of whether to use them can be based on the expected network conditions, and need for complex gesturing.

State of report (not started, started, finished) was not apparent (3)

The site and victim report forms remained in a disabled, greyed out, state until 'started search' or 'found victim' was selected. They then became active, and details could be entered, and the report submitted. These stages were not salient enough for some participants, so the reports should be redesigned so that the state is apparent from farther way, and at a glance. As a general point, because the tabletop display is large and high-resolution it can contain a large amount of information, so displays should be designed so they make sense up close, and also at a glance. This is similar to designing a poster at a conference that conveys a message from the other side of the room, and reveals more detailed information when one walks over to take a closer look.

Ability to see other person entering report was useful (2)

Ability for both people to enter reports was useful (1)

Trying to enter a report for the search unit is probably not a good idea (3)

It was considered useful to be able to follow the other person's progress as they entered a report, but when both people try to modify a report simultaneously there is potential for mistakes to be made. Viewing of the other person's display could be implemented, but there should probably be some kind of concurrency control to stop two people simultaneously editing a report.

Tactical did not (or hardly) used over-the-shoulder view (OSV) (3)

OSV was useful because it reminded tactical of restricted handheld display (3)

Tactical input to OSV may not be a good idea (2)

The over-the-shoulder view (OSV) showed a copy of the handheld display on the tabletop. For an example of the OSV, see the left of Figure 1(a). Some users of the tabletop did not use the OSV at all, whereas others found it very useful. Although it was interactive and could be used to remotely control the handheld, it was mainly useful for viewing the handheld interface, not for controlling it. Moreover, using it for control was identified as a bad idea by two participants. It seems that the *view* part of the OSV is a useful part of the collaborative system, but the *control* would probably best be left out.

Visibility regions were useful (3)

It was useful to know tactical was aware of my map position/could pan it (3)

Visibility region obscured items underneath (1)

Generally the visibility regions (Figure 19) were found to be useful. Some teams found the ability to pan the handheld map from the tabletop to be useful—around half of the teams used this feature.

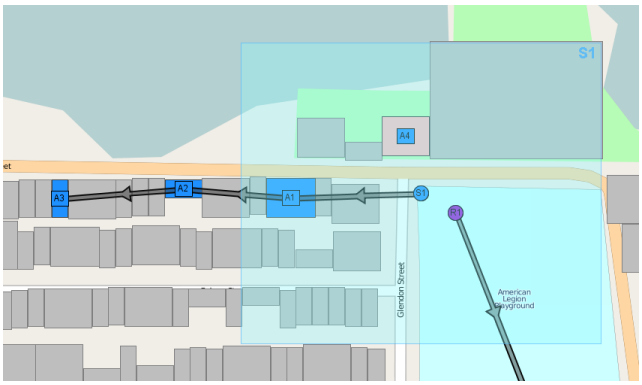


Figure 19: The visibility region (blue rectangle) indicating the portion of the map shown on the searcher's display was found to be useful, but it did add clutter to the map.

Search unit did not use timeline (11)

Most of the search units in the two-person experiment stated that they did not use the timeline. The timeline was mainly a tool for the tactical actor to make a schedule of tasks, and the constant attention that the searcher was afforded by tactical in the two-person teams meant that he could easily ask about the next ask rather than looking it up on the timeline.

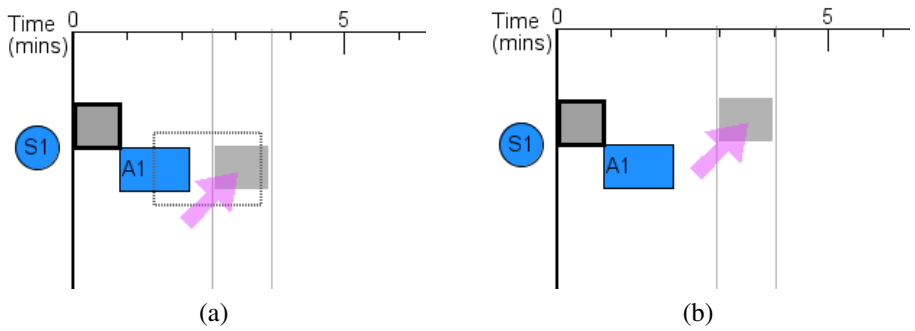
Difficult to drag and drop tasks on timeline (3)

Tasks were arranged on the timeline by the tactical actor by dragging and dropping them with the pen. Several users of the tabletop had problems arranging the tasks, because of a problem in the interface's design, whereby the areas onto which tasks had to be dropped were too small (Figure 20). Although the areas did highlight when the pen was moved over them, users did not notice this subtlety when they were under time pressure. The areas should be made larger, to include all styles of dragging and dropping exhibited by users.

3.3 Suggestions

Extra cues to draw the user's attention (5)

Extra cues, particularly audio cues, were suggested by users of the tabletop and handheld, to draw their attention to events such as a new task appearing, or a task exceeding its estimated time. On the



(a) (b)

Figure 20: Target areas for drag-and-drop were too small. If the task was dragged to the correct region on the timeline (a) the region was highlighted and the task could be dropped. However, if the task was dragged to another location (b) the drag-and-drop action was ignored.

tabletop, because the display is so large, the user may not notice that some item requires attention. On the handheld, the user may be looking away from the device, concentrating instead on navigating the environment. Tactile cues on the handheld were suggested by one participant. This could be very useful for a handheld device in a real mission, and could be provided by the vibration device found in many mobile phones.

Activity indicator for search unit (running/walking/standing/searching) (1)
It would have been useful for the tactical actor to have activity awareness information shown continuously on the tabletop, so he could remain aware of the status of the team members without asking them. Satellite positioning and accelerometers could be used to determine whether a person is standing, walking, or climbing. Other sensors might be used to provide more detailed information. This could be displayed next to a person's symbol on the map, either as text, or using some graphical icons. This would be analogous to similar awareness features that are very useful in instant messaging and audio conferencing systems, which show whether a person is writing or speaking now, and show a person as idle if they do not make any action for some time.

Compass direction for search unit (8)
Many participants in the search unit role suggested a compass on the handheld device. Small compass devices are now available for handheld devices that would be very useful in this scenario, and should be included in a final system. Compass functionality was deliberately omitted from this experiment, to give participants a challenge when navigating. A compass direction for a search unit shown on the map would also have been useful for the tactical actor when giving directions.

Heading-up map (as opposed to north-up) (2)
Some participants requested a heading-up map, that is, one that rotates so that up on the map is the direction in which they are moving. North-up was chosen instead, because the map is shared between participants, and having a common orientation means that it should be easier to refer to the map in conversation. The north-up map retains the what-you-see-is-what-I-see principle. This choice is an example of the trade-off between design for individuals and design for groups (Gutwin & Greenberg, 1998).

New method for making a route (draw it, or drag from existing route) (2)
The method of adding and removing waypoints from a route on the map using pen gestures caused frustration for some users when they had to use it under time pressure. A method that avoids sketch recognition, perhaps by adding a waypoint when dragging the middle of a route, would be an improvement. Various such methods have been demonstrated in mapping services such as Google Maps, and one of those could be adapted for collaborative use.

Completed routes should be removed from map (3)
In the scenario they were given, participants had no reason to review completed routes, so these could have been removed from the map. Reducing clutter is an issue as missions become more complex. Clutter from annotations is also an issue, which could be addressed by providing a tool to easily delete large regions of annotations, or an option to delete all annotations on the map.

Drag-and-drop symbols on map (7)
The only way participants could annotate the map was using freehand drawing with a pen or finger. Many of the annotations were the same, for instance, marking blocked roads, so a set of commonly used symbols would have improved the neatness and accuracy of the map, and made it easier for the handheld user to provide useful annotations. The symbols would need to be prepared in advance for common incident types.

Semi-automatic route planning (2)
Semi-automatic scheduling of tasks (2)
Automation was intensionally left out of this system because the focus was on the person-to-person collaboration. A final system should include some automation for arranging tasks in the timeline, and creating routes on the map. The route planning could provide an initial route that is the shortest distance on known roads that avoids marked blockages. The scheduling could automatically assign the next pending task, by inserting it into the position that causes the minimum expected increase in overall time. These functions should not be fully automated, because the system must remain

flexible, and cope with the unexpected needs that will arise in emergency situations.

Camera view from operational unit (4)
Several participants suggested having a camera view from the search unit viewable on the tabletop. This would be a useful feature at times, but care should be taken not to overwhelm the tactical actor when the team size increases. Also, it would also require significant network capacity to carry the video streams.

3.4 Differences from three-person team

Qualitative feedback from the three-person experiments was obtained from questionnaires, observations, and videos of the participants completing the missions. Two teams (six people) participated in these experiments, so there are not enough results to show statistical significance in the measurements. The people in the three-person experiments all also participated in the two-person experiments, so we can compare some results between the two experiments. Appendix E shows the subjective workload in the two-person and three-person experiments. Generally, the workload is at least as high in the latter case, but there is no other obvious difference.

Below are some differences between the two and three-person teams that were raised by the qualitative results.

Scalability of tactical role
The workload of the tactical actor rises as more search units are added, and with just two search units the task of co-ordinating them is a challenge. Semi-automatic scheduling and routing, as described above in Section 3.3, would be important for a larger team. One of the searchers was comfortable using the simulated environment, and commented that he would have tried to help by choosing his own route, but he wasn't aware of the wider concerns of the team so he left the tactical actor to choose his route for him. The tactical actor is the bottleneck for the team, so optimising his work is a priority.

Contention for the audio channel
Because there was more contention for the single shared voice channel, participants were more concise when giving status updates. Searchers tended to give less feedback when things were going well, only contacting the tactical actor when there was a problem.

Autonomy of operational actors
When the team size was increased to three, searchers had to be more autonomous because they did not have the individual attention from the tactical actor that they had before. They tended to start moving, inform tactical of what they were doing, and keep listening for more detailed instructions. Searchers tended to use the timeline to see which task they had to do next, as opposed to the previous experiment where they almost never used the timeline.

Visual clutter
Clutter on the map was a problem in the three-person teams. The two searchers' annotations were both blue, which led to some confusion over who had made a particular mark on the map. Similarly, the routes for the two of them looked the same, which caused some confusion when two units were routed along the same street. Old routes added clutter, as did the workspace awareness features—particularly the visibility regions.

Switching attention
The tactical actor arranged his attention by switching it from one search unit to the other. This behaviour could be supported explicitly by having map views tailored to a particular unit, and switching between them. This would address the problem of clutter, because only one search unit's information would be visible at a time. A column of panels, one for each search unit, could be a good way to keep the status information, and possibly the over-the-shoulder views, of each of them in a neat arrangement and allow easy switching between them.

3.5 Conversation analysis

This section presents an example of the findings of conversation analysis applied to the guiding task. It is an initial result from the analysis, which is ongoing at the time of this report's being written. The description here is paraphrased from a write-up provided by Menisha Patel of King's College.

The transcript below is from midway through the task, as S (the participant with the handheld device) moves through the simulated urban environment describing objects he sees, and T (the participant at the tabletop) annotates the map to indicate security issues. Appendix F contains a guide to the transcript notation.

```
S: They're one, two, three, they're five storey buildings on my,
   on my right, and these are the ones, they're, they're the
   ones you're marking now.
T: Yup
S: Um, now a bit further on I've got some three storey buildings
   on my left, which are these. That's where my hand is. And then
   a bit further on still there's um a, on my left is another
   skyscraper coming up. I'm going to re-centre [my screen okay
T:                                               [hang on
```

S describes in detail the buildings he finds as he slowly moves through the environment. It is up to T to annotate these observations on the map projected on the tabletop. He does so using the pen.

What is interesting is the change in orientation of T's pen during this time. As S begins to discuss the buildings that can be seen, T holds the pen in a similar orientation to that which one would when using a manual writing implement (Figure 21(a)). His thumb rests on the left side of the pen and his forefinger on the right, near to its base. His hand rests on the map as he annotates it according to what S mentions. Since this is the initial hand position and is so similar to the conventional manner of holding a pen, it may reflect T's preferred hand position.

(a) (b) (c)

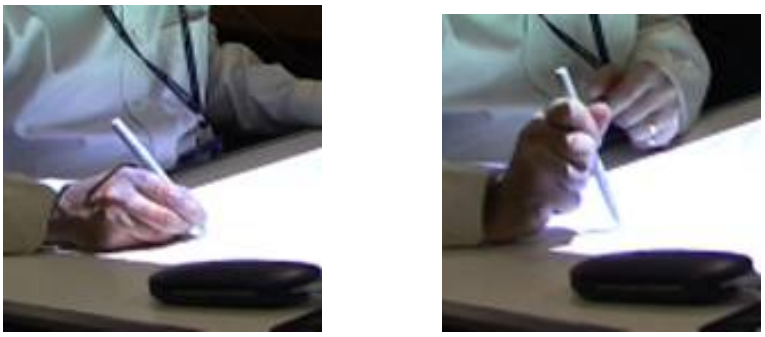
Figure 21: Changing hand position.

As S continues to talk and move around the environment, T alters the orientation of his hand (Figure 21(b)). He moves his hand further up the pen, and moves his palm slightly off the map as he writes. As a result of this movement, his grip on the pen shifts away from the conventional grip.

Following this, T moves his hand up to a new orientation as the discussion continues (Figure 21(c)). Here he holds the pen almost at its upper point, completely different from the initial low positioning. His grip on the pen changes according to this movement. This new position is a shift away from how one would generally hold a pen when writing or annotating a document.

The map can contain much information in a small area. There are roads and buildings, a blue circle indicating the location of S, blue annotations from S, and purple annotations from T. Also, T was keen to use his telepointer to gesture while talking, so there were many details to show, and a clear view of the map was pivotal for fluid interaction.

This clear view is obstructed at times by the shadow created by Ts hand. The shadow (Figure 22(a)) obscures a portion of the map, so T cannot see part of the area which is relevant to the discussion. He gradually finds an orientation of the pen that will create a minimal shadow as in Figure 22(b).



(a) (b)

Figure 22: Alteration of grip to minimize shadow.

The electronic pen is designed to emulate the use of conventional writing implements. However the changing hand positioning used to combat the shadow means that there is an altered grip on the pen.

This problem of obscuring the projection was, on another occasion, explicitly stated by T. Nearing the completion of the task, the participants must reconsider the route according to all the security risks that have been discovered. Since S has only a small view on the handheld device, T begins to reconsider the route single-handedly. Having identified a possible alternative for part of the route, he begins to draw it on the map.

```
S: I can't see anything at the moment what you're doing <T>
T: No, I think this is just between me and the ...
S: ... what you're
T: Since I'm drawing I'm now getting a problem with the shade in
    that I can't see it. This would definitely be much better with
    a mouse.
```

As T begins to draw, he utters in a frustrated tone that there is an issue with the "shade". Figure 23 indicates that there is in fact a large shadow that falls across the map when T attempts to reformulate part of the route. In order for this reformulation to take place, a consideration of the whole of that particular area is required simultaneously by T, and the shadow raises problems. Again, T uses an unconventional grip on the pen, holding it at the top. This may alter the nature in which participants write.

Figure 23: A shadow falls across the map.

The shadow created by front projection on the tabletop is problematic for interaction in some cases. Where the shadow falls there is complete darkness so participants may have no recollection of what is underneath. On paper the darkness of shadow is not usually so exaggerated, so participants can see to an extent what it underneath. As the participant reaches out further, the arm further obscures the projection, creating a larger shadow. This means at times participants may not be able to annotate

and see the map simultaneously. The shadow also has implications for the manner in which the pen is held. To minimise the shadow the participant holds the pen near the top. This may have implications for overall control, satisfaction, and ability to write well.

None of the participants in any of the experiments mentioned this problem to the experimenter or wrote about it in their questionnaires. It is an example of an issue that may only be noticed by watching participants use the technology. People are used to having paper documents illuminated from above, and to moving their hands away to avoid shadows, so it is possible that experimental participants did not perceive the shadows as an issue with the technology itself. The problem of shadows will be removed in future systems by the use of rear projection or flat panel displays. The problem of occlusion of information by the hands and arms of the user will remain for any tabletop display. New user interface techniques should be developed to alleviate this problem.

4 Conclusion

In this series of experiments, participants completed simulated urban search and rescue (USAR) and guiding tasks in teams of two or three people. They used shared workspaces on tabletop and handheld displays, which optionally included workspace awareness features (WAFs) designed to support synchronous collaboration over the visual information.

Participants preferred to have the WAFs on the map. On the reports, they preferred them in the two-person USAR experiment, but not in the three-person experiment. This may be because in the three-person case the searchers needed to be more autonomous so they completed the reports themselves rather than collaborating on them. In neither experiment were the WAFs preferred on the timeline. This may be because responsibility for scheduling tasks was always left to the tactical actor, so there was nothing to discuss about the timeline.

Having the WAFs led to more deictic gesturing. Participants used a variety of strategies for referring to locations and direction on the map. We counted 12 strategies.

A sketch-based interface was included for manipulating waypoints on the map. This caused problems because the inevitable recognition errors were exacerbated by the time pressure put on users by the mission. A technique such as dragging waypoints out from existing routes could have avoided this problem. Mode confusion on the map was a problem. The tabletop display is large enough that the toolbar was often outside the user's field of view, so he could not easily see the cause of the problem. A more salient display of the modes, or a redesign of the interface to avoid the use of modes, could address this problem.

In an actual emergency response organisation the span of control is generally six or seven, meaning that the tactical actor at the tabletop display may be co-ordinating up to seven operational units. Several issues for scalability were found. Some automation to aid scheduling tasks and routing around the map will be required. Clutter on the map was a problem, and there are various possible approaches to this, including switching among the different search units, and clearing obsolete information.

Participants used more concise speech when the team size increased, and avoided using the strategies for reporting that involved much talking on the voice channel, choosing instead for the search unit to enter all information.

The over-the-shoulder view (OSV) is a feature that shows a copy of a linked handheld display on the tabletop. Many participants found it useful, saying that it reminded them of the very different view that the handheld user was seeing. However, the OSV may be better as a read-only display, because input to the OSV on the tabletop is a potential source of confusion.

APPENDIX

A USAR experiments with three-person teams

The two-person USAR experiment is explained in Deliverable D3 (Ashdown, 2008a), and the questionnaires given to participants are included in that document. For the three-person experiment, participants were given pre-mission questionnaires with the same Likert-scale questions but without open-ended questions. These questionnaires are shown below, followed by the final questionnaire that participants were given at the end of the experiment.

Post-mission questionnaire

Participant number: _____ Condition: _____

For all multiple choice questions, please choose the one answer that provides the best response.

	strongly disagree 1	somewhat disagree 2	neither agree nor disagree 3	somewhat agree 4	strongly agree 5
1. My team was successful in accomplishing its mission.	☐	☐	☐	☐	☐
2. The members of my team worked together effectively.	☐	☐	☐	☐	☐
3. I found the task mentally demanding.	☐	☐	☐	☐	☐
4. I found the pace of the task to be fast.	☐	☐	☐	☐	☐
5. I had to work hard to accomplish the mission.	☐	☐	☐	☐	☐
6. I became frustrated during the mission.	☐	☐	☐	☐	☐
7. The workspaces we used (map, timeline, and reports) helped us achieve our goal.	☐	☐	☐	☐	☐
8. The ability to speak to each other was useful.	☐	☐	☐	☐	☐
9. The ability to share visual information with each other was useful.	☐	☐	☐	☐	☐

	strongly disagree	somewhat disagree	neither agree nor disagree	somewhat agree	strongly agree
	1	2	3	4	5
10. The map provided useful information for me.	☐	☐	☐	☐	☐
11. The map was useful for collaboration with the other team members.	☐	☐	☐	☐	☐
12. The ability to annotate the map was useful.	☐	☐	☐	☐	☐
13. The timeline provided useful information for me.	☐	☐	☐	☐	☐
14. The timeline was useful for collaboration with the other team members.	☐	☐	☐	☐	☐
15. The site and victim reports were useful for collaboration with the other team members.	☐	☐	☐	☐	☐
If workspace awareness features were enabled, go to question 16, otherwise go to question 21.					
16. The over-the-shoulder view (copy of the handheld display on the tabletop) was useful for collaboration.	☐	☐	☐	☐	☐
17. The telepointers were useful for collaboration.	☐	☐	☐	☐	☐
18. The traces were useful for collaboration.	☐	☐	☐	☐	☐
19. The visibility regions were useful for collaboration.	☐	☐	☐	☐	☐
20. The highlighting of symbols was useful for collaboration.	☐	☐	☐	☐	☐
21. The highlighting of symbols was useful for me individually.	☐	☐	☐	☐	☐

After the two missions were complete, a final two-page questionnaire asked the participants of the three-person USAR teams for their preference between the two conditions (with and without workspace awareness features). It also had some extra open-ended questions specifically about how the system could scale up to larger teams. This questionnaire is shown below.

Preference questionnaire

Participant number: _____

You have completed missions with two versions of the remote collaboration technology – without and with the workspace awareness features. For each question choose which of the two versions you prefer, or choose the middle option to indicate no preference.

	Version **without** workspace awareness features	No preference	Version **with** workspace awareness features
1. Which version of the **map** better supported your collaboration?	☐	☐	☐
2. Which version of the **map** was easier for group work?	☐	☐	☐
3. Which version of the **timeline** better supported your collaboration?	☐	☐	☐
4. Which version of the **timeline** was easier for group work?	☐	☐	☐
5. Which version of the **reports** better supported your collaboration?	☐	☐	☐
6. Which version of the **reports** was easier for group work?	☐	☐	☐
7. Which version did you prefer overall?	☐	☐	☐

8. Were there any problems with the tactical actor switching his/her attention between the two search units? Did the workspace awareness features help this switching?

9. Compared to the previous two-person team, how was working in this three-person team different? How did you alter your behaviour from the previous experiment?

10. How do you see this system scaling up to seven search units?

11. Any other comments.

B Guiding Task

The following two-page instructions were given to the participant at the tabletop during the guiding task described in Section 1.1.3. They are included here to give an idea of what the task entailed. Similar instructions were given to the participant using the handheld. The tabletop user was also given a textual description of the route to check.

Route Planning Experiment

Instructions for Participant A

You work for a security organisation in Boston. Today a well known politician, whose recent controversial remarks mean that he is facing high security threats, is due to visit.

A top-secret route has been handed to you. It is your task based here at the table top, alongside another member of the organisation based on the ground, to determine whether the route that has been selected is suitable for the politician to be transported along.

In order to determine this suitability there are certain key aspects to your task:

- Using the **Direction Sheet** direct your co-worker along the route. As you do this it will be useful to mark the route on your electronic map, for reference.

- Consider very carefully anything that may be perceived as a security risk along the way.
    - Security risks may include (these are some examples):
        - *Tall buildings*; because there are too many windows to check.
        - *Parked Cars, and other vehicles*; they may contain bombs, etc.
        - *Bins, other large containers*; may contain bombs, etc.
        - *Bushes, other concealed areas*; may be hidden people in there.

- It is up to you and your partner to decide whether something warrants a risk. Note down the risk, and the reasoning for your selection of it on the paper that you have been provided with. Remember some things in the environment may be good to have on the route, including police cars for instance as they offer protection.

1

Having scrutinised the route, you may suggest alternative roads that could be used to transport the politician. Mark these on the map and also note them down on the paper that has been provided. It may be good to give reasoning as to why these have been chosen as an alternative.

At the end of the task, you should provide:

- A list of Security Risks/Good Objects on the route, and reasoning behind why these are considered so. These can be written on the paper provided.
- Alternate Directions marked on the map, and noted on the paper provided. There should be reasons as to why they are a preferred alternative to the chosen route also noted down.

You have a maximum of 30 minutes to complete the task.

The two-page questionnaire given to participants at the end of the guiding task is shown below.

Post-mission questionnaire

Participant number: _____ Role: _____

For all multiple choice questions, please choose the one answer that provides the best response.

	strongly disagree 1	somewhat disagree 2	neither agree nor disagree 3	somewhat agree 4	strongly agree 5
1. The ability to speak to each other was useful.	☐	☐	☐	☐	☐
2. The ability to share visual information with each other was useful.	☐	☐	☐	☐	☐
3. Seeing the operational unit's location (blue circle on the map) was useful.	☐	☐	☐	☐	☐
4. Having the shared interactive map is an improvement over simply showing the blue circle on everyone's map.	☐	☐	☐	☐	☐
5. The ability to annotate the map was useful.	☐	☐	☐	☐	☐
6. The telepointers (for pointing at the map) were useful.	☐	☐	☐	☐	☐
7. The visibility regions were useful.	☐	☐	☐	☐	☐
8. The over-the-shoulder view (copy of the handheld display on the tabletop) was useful.	☐	☐	☐	☐	☐
Just for the tabletop user					
9. The use of a tabletop display, instead of a conventional PC, was helpful for this task.	☐	☐	☐	☐	☐

Please turn over

10. How do you think having the map-sharing technology would change your style of collaboration when compared to just having the voice communication and paper maps?

11. What problems were there with the map-sharing technology?

12. What extra features would have helped you with this task: what would you add?

13. Any other comments.

C Open-ended responses

The following table lists feedback that participants wrote in response to the open-ended questions in the questionnaires. The numbers indicate how many participants expressed the idea. There were 13 participants in the search role, and 13 in the tactical role, making a total of 26 for both.

Feedback	Search	Tactical	Both
Map			
It's not obvious which tool is selected	1	0	1
Difficult to add/delete waypoints	0	2	2
Search unit icons not salient enough	0	1	1
Waypoints and routes too big (too salient)	0	1	1
Timeline			
Search unit did not use timeline	11	0	11
Timeline not useful for tactical	0	1	1
Timeline not useful for communication	0	1	1
It was difficult to drag and drop tasks in the timeline	0	3	3
Completion of tasks in timeline was not clear	1	0	1
Highlight of unscheduled tasks was not salient enough	0	1	1
Reports			
Search unit didn't use reports	0	2	2
State of report (not started, started, finished) was not apparent	1	2	3
Ability to see the other person entering report information was useful	1	1	2
Trying to enter a report for the search unit is probably not a good idea	1	2	3
Ability for both people to use the reports was useful	0	1	1
Confusion between the half-cross/full-cross symbols on site report	0	2	2
Problem with precision of touch input on handheld for reports	1	0	1
Workspace Awareness Features (WAF)			
Traces were useful	1	1	2
Traces were distracting / not useful	0	2	2
Trace was confused with annotation	0	3	3
Telepointers were distracting	0	1	1
Participants used annotations instead of the trace	1	0	1
Tactical did not (or hardly) used over-the-shoulder view (OSV)	0	3	3
Tactical input to OSV may not be a good idea	1	1	2
OSV was useful because it reminded tactical of restricted handheld display	1	2	3
WAF useful because I could see what the other person was doing/seeing	1	2	3
Visibility regions were useful	1	2	3
Visibility region obscured items underneath	0	1	1
Was useful to know tactical was aware of my map position and pan it as necessary	2	0	2
Was useful that tactical could change views for me	1	0	1
Other			
Drawing on tabletop fiddly	0	1	1
Drawing on handheld was difficult	2	0	2
Difference between search unit blue and rescue unit purple was not salient	0	1	1
Things that are drawn on the map but not announced verbally go unnoticed	1	0	1

The following table lists suggestions that participants wrote in response to the open-ended questions in the questionnaires. The previous 'feedback' table lists issues with the existing remote collaboration system, whereas this 'suggestions' table lists possible changes. The numbers indicate how many participants expressed the idea. There were 13 participants in the search role, and 13 in the tactical role, making a total of 26 for both.

Suggestion	Search	Tactical	Both
Map			
Compass direction for search unit	6	2	8
Indicator of GPS error (circle around location)	1	1	2
Activity indicator for search unit (running/walking/standing/searching)	0	1	1
Handheld map should follow position of operational unit	4	0	4
Heading up map (as opposed to north up)	2	0	2
Indication of North direction	0	1	1
Snap waypoints to map points	0	1	1
Ability to plan route from current position rather than last site	1	0	1
New method for making a route (draw it, or drag from existing route)	1	1	2
Completed routes should be removed from map	1	2	3
Ability to add text to map	0	1	1
Ability to add buildings etc. to map	0	1	1
Extra information on the map for identifying buildings (e.g. landmarks)	3	0	3
Number all buildings, for easy reference	1	0	1
Location of entry points of buildings on map	2	2	4
Ability to zoom map	2	2	4
Aerial photography	1	2	3
Drag-and-drop symbols on map	2	5	7
Information on road blocks prior to arrival (indicate off-screen symbols)	1	0	1
Ability to clear all annotations	0	1	1
Timeline			
Ability to prioritise rescue tasks	0	1	1
Display report from timeline by clicking corresponding task	0	1	1
Timeline should automatically pan to 'now'	1	0	1
Reports			
Should not be necessary to select Found victim before editing the victim details	0	1	1
Better way for selecting age in victim report (+/- 10, choose an age range, hold down the button, etc.)	5	4	9
Female/male selection should have radio buttons, not up and down arrows	1	1	2
Ability to indicate sub-task progress (tick off rooms/floors)	0	1	1
Site report buttons: icons, to make finding a button easier	1	0	1
Site report buttons: toggling between three states should be replaced by another method	1	1	2
Site report buttons: should be in alphabetical order. Took some time to find buttons.	2	1	3
Lock report when someone else is accessing it	1	1	2
Allow corrections to submitted reports	0	2	2
Victim report should also contain a site summary in the available space	0	1	1
Leave previous site report on screen	1	0	1
Cues			
Notification of task going over it's estimated time (e.g. audio cue)	1	1	2
Map should contain information about remaining time for current task	1	0	1
Audio cue when pending tasks appear	0	1	1
Audio cue when something happens	1	1	2

Suggestion	Search	Tactical	Both
Automation			
Semi-automatic route planning	0	2	2
Semi-automatic scheduling of tasks	0	2	2
Visual and Interaction Design			
Telepointers should be more salient	1	1	2
Match all cursors to tool icons	0	1	1
Bigger buttons on handheld	1	0	1
Key for the meaning of colours (e.g. late/early on timeline)	0	1	1
Key to meaning of icons in site report	1	0	1
Auto align windows (rotation was not needed)	0	1	1
Would like to have fewer windows, with more on each one	0	1	1
Ability to minimize over-the-shoulder view	0	1	1
Over-the-shoulder view probably not a good idea. Have reports for all searchers in a column. Other info is shown on map and timeline.	0	1	1
Avoid use of modes for tabletop	0	2	2
Avoid using buttons on pen	0	1	1
Use buttons in left hand to modify actions of right hand with pen	0	1	1
New Features			
Camera view from operational unit	1	3	4
Notepad on tabletop	0	1	1
Ability to review past actions/locations	1	0	1
Stylus input on handheld	1	0	1

D Statistics

The conversation of participants in the two-person USAR experiment was analyzed to produce word counts for several utterance types in the two conditions (referred to here as synchronous and asynchronous). They were analyzed in SPSS Statistics. The means and standard deviations of the counts, and the results of a paired-samples t-test, are in the tables below.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Feedback.Async	115.31	13	46.686	12.948
	Feedback.Sync	98.31	13	63.597	17.639
Pair 2	Guide_Both.Async	332.77	13	197.404	54.750
	Guide_Both.Sync	297.62	13	162.437	45.052
Pair 3	Guide_Deitic.Async	16.23	13	13.535	3.754
	Guide_Deitic.Sync	82.92	13	59.892	16.611
Pair 4	Guide_Nondeitic.Async	316.54	13	197.242	54.705
	Guide_Nondeitic.Sync	214.69	13	139.049	38.565
Pair 5	Meta.Async	35.08	13	34.531	9.577
	Meta.Sync	48.54	13	77.605	21.524
Pair 6	Other.Async	4.38	13	7.252	2.011
	Other.Sync	9.69	13	24.133	6.693
Pair 7	Report.Async	57.38	13	57.237	15.875
	Report.Sync	63.31	13	72.526	20.115
Pair 8	SA_Both.Async	94.77	13	61.195	16.973
	SA_Both.Sync	85.46	13	50.034	13.877
Pair 9	SA_Deitic.Async	16.85	13	19.454	5.396
	SA_Deitic.Sync	18.62	13	17.481	4.848
Pair 10	SA_Nondeitic.Async	77.92	13	57.916	16.063
	SA_Nondeitic.Sync	66.85	13	45.277	12.557
Pair 11	Social.Async	12.15	13	17.170	4.762
	Social.Sync	4.92	13	7.889	2.188
Pair 12	Status.Async	355.00	13	203.684	56.492
	Status.Sync	330.69	13	214.063	59.370

Paired Samples Test

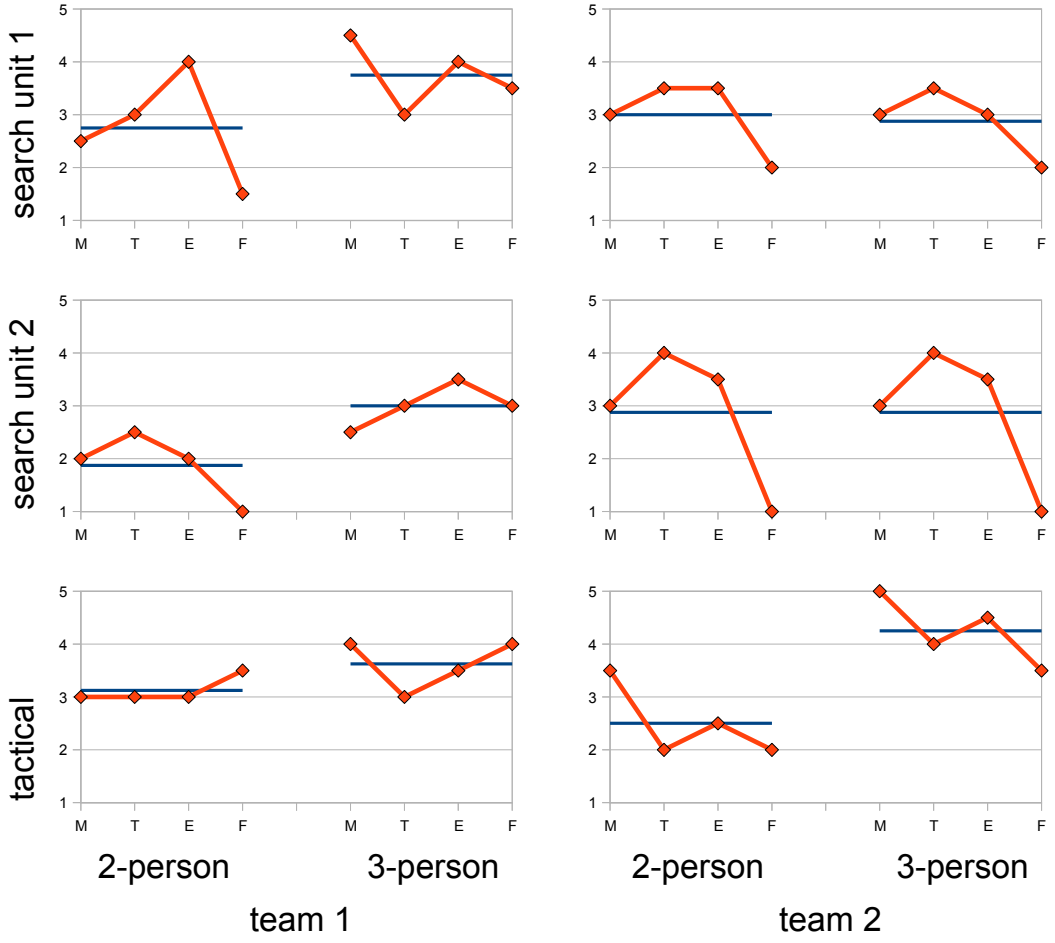
		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Feedback.Async - Feedback.Sync	17.000	57.290	15.889	-17.620	51.620	1.070	12	.306
Pair 2	Guide_Both.Async - Guide_Both.Sync	35.154	216.635	60.084	-95.757	166.065	.585	12	.569
Pair 3	Guide_Deitic.Async - Guide_Deitic.Sync	-66.692	55.020	15.260	-99.941	-33.444	-4.370	12	.001
Pair 4	Guide_Nondeitic.Async - Guide_Nondeitic.Sync	101.846	196.165	54.406	-16.695	220.387	1.872	12	.086
Pair 5	Meta.Async - Meta.Sync	-13.462	66.663	18.489	-53.745	26.822	-.728	12	.481
Pair 6	Other.Async - Other.Sync	-5.308	25.542	7.084	-20.743	10.127	-.749	12	.468
Pair 7	Report.Async - Report.Sync	-5.923	55.825	15.483	-39.658	27.812	-.383	12	.709
Pair 8	SA_Both.Async - SA_Both.Sync	9.308	66.329	18.396	-30.775	49.390	.506	12	.622
Pair 9	SA_Deitic.Async - SA_Deitic.Sync	-1.769	12.524	3.474	-9.338	5.799	-.509	12	.620
Pair 10	SA_Nondeitic.Async - SA_Nondeitic.Sync	11.077	62.842	17.429	-26.898	49.052	.636	12	.537
Pair 11	Social.Async - Social.Sync	7.231	18.494	5.129	-3.945	18.407	1.410	12	.184
Pair 12	Status.Async - Status.Sync	24.308	184.847	51.267	-87.394	136.010	.474	12	.644

E Subjective workload against team size

The graphs below shows the average subjective workload responses for the two-person (Section 1.1.1) and three-person (Section 1.1.2) experiments, for the six participants of the three-person experiments. All six of them participated in the two-person experiments with the same role.

The responses were averaged over the two conditions. The labels M, T, E, and F denote the subjective evaluation of mental workload, time pressure, effort required, and frustration (questions 3–6 in Appendix A). The horizontal lines show the means of the four values.

The results suggest that the participants found the three-person missions the same or harder than the two person ones.



F Transcript notation

The results in this report contain several transcripts of conversations between experimental participants, so here is a brief guide to the notation used.

Speech is preceded by a letter for the person who spoke. T for the tactical actor at the tabletop, and S for the search unit. In the three-person teams, there are two search units, S1 and S2.

```
S2: Victim
T: OK
```

References to figures are in parenthesis.

```
S: (a) OK, I'm out (b)
```

Actions are also in parenthesis.

```
S: I have found a victim on the ground floor.
   Gender female, age sixty eight.
T: (Enters details on report)
S: Yeah, that's it.
T: (Submits report)
```

A left bracket indicates words that were spoken simultaneously.

```
T:  And [you'll see A [3.
S:      [OK           [oh A3.
```

Where the real name of a participant was used, it has been replaced by the person's symbol to avoid making the person's identity public.

```
S: I can't see anything at the moment what you're doing <T>
```

References

Ashdown, M. (2007, October). *Asymmetric distributed collaboration in emergency response.* (Deliverable D1 of EC Marie Curie OIF project 21743)

Ashdown, M. (2008a, September). *Design of experiments for asymmetric distributed collaboration.* (Deliverable D3 of EC Marie Curie OIF project 21743)

Ashdown, M. (2008b, March). *Implementation of asymmetric distributed collaboration.* (Deliverable D2 of EC Marie Curie OIF project 21743)

Bigley, G. A., & Roberts, K. H. (2001). The Incident Command System: High-Reliability Organizing for Complex and Volatile Task Environments. *Academy of Management Journal*, *44*(6), 1281–1299.

Diamant, E. I., Fussell, S. R., & Lo, F.-L. (2009). Collaborating across cultural and technological boundaries: team culture and information use in a map navigation task. In *Iwic '09: Proceeding of the 2009 international workshop on intercultural collaboration* (pp. 175–184). New York, NY, USA: ACM.

Gutwin, C., & Greenberg, S. (1998). Design for Individuals, Design for Groups: Tradeoffs Between Power and Workspace Awareness. In *Proceedings of CSCW 1998* (pp. 207–216).

Gutwin, C., & Greenberg, S. (1999). The Effects of Workspace Awareness Support on the Usability of Real-Time Distributed Groupware. *ACM Transactions on Computer-Human Interaction*, *6*(3), 243–281.

Gutwin, C., & Penner, R. (2002). Improving Interpretation of Remote Gestures with Telepointer Traces. In *Proceedings of CSCW 2002* (pp. 49–57).