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ALTERNATIVE VISUALIZATION METHODS IN URBAN OPERATIONS: IN-BUILDING TERRAIN ENVIRONMENT

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Abstract

This study compares 2D and 3D representations of in-building environments for visualization and mission rehearsal. Twelve infantry soldiers were assigned to use a floor plan to learn a mission within the buildings and twelve were assigned to learn the same mission using the 3D virtual environment. Another twelve soldiers received only a verbal description of the mission, with no visual representation of the buildings. After the learning period, soldiers completed their mission in the actual buildings. Each soldier completed the experiment, first at night and then again the following day, using a different route through the buildings.

Qualitative data was gathered in the form of pre-mission and post-mission questionnaires, comments and focus groups. Mission performance measures, including visualization time, route time, route distance, terrain reconstruction drawings and bearing estimation errors to critical mission features, were also gathered.

Overall, qualitative results indicated that the floor plan and virtual environment were both better than no aid at all. Quantitative results showed that performance for the floor plan group was better than the virtual environment group for many mission performance measures. There were no measures, qualitative or quantitative, where performance using the virtual environment was significantly better than performance with the floor plan.

Several information requirements were identified as vital to the development of a mental model, regardless of the visualization method, including staircase locations, room information, door information, interior room layouts, scale and distances, directional information and an overhead view of the floor plan. The interface design of any future visualization tool should include these features. Areas for future investigation are suggested and opportunities for visualization tool development are suggested.

Résumé

Cette étude compare des représentations 2D et 3D d'environnements intérieurs de bâtiments pour les visualiser et se préparer à des missions. On a demandé à douze soldats d'utiliser un plan d'étage pour apprendre une mission à l'intérieur de bâtiments et à douze autres d'apprendre la même mission à l'aide d'un environnement virtuel 3D. Douze autres soldats n'ont reçu qu'une description orale de la mission, sans représentation visuelle des bâtiments. Après la période de formation, les soldats ont accompli leur mission dans les bâtiments. Chaque soldat a effectué l'expérience une première fois la nuit, puis une seconde fois le lendemain, en suivant un parcours différent dans les bâtiments.

Des observations qualitatives ont été recueillies à partir de questionnaires de préparation à la mission et de compte rendu de mission, de commentaires et de groupes de discussion. Les mesures de la performance en cours de mission, y compris le temps de visualisation, le temps de parcours, la distance de parcours, les dessins de reconstitution du terrain et les erreurs d'estimation de la position par rapport aux directions critiques à la mission, ont aussi été recueillies.

En général, les observations qualitatives ont indiqué que le plan d'étage et l'environnement virtuel sont tous les deux plus utiles qu'aucune aide. Elles ont aussi révélé que la performance du groupe qui avait étudié le plan d'étage était supérieure à celle du groupe qui avait étudié l'environnement virtuel pour de nombreuses mesures de performance en cours de mission. Aucune mesure qualitative ou quantitative de la performance du groupe ayant étudié l'environnement virtuel n'était nettement supérieure à celle du groupe ayant étudié le plan d'étage.

Plusieurs besoins en information ont été identifiés comme étant essentiels à la conception d'un modèle mental, peu importe la méthode de visualisation, notamment l'emplacement des escaliers, l'information sur les pièces et les portes, l'aménagement intérieur des pièces, l'échelle et les distances, l'information directionnelle ainsi qu'un plan d'étage vu du haut. La conception d'une interface d'un outil de visualisation devrait inclure ces besoins. Des champs d'étude futurs ainsi que des possibilités de mise au point d'outils de visualisation sont suggérés.

Executive Summary

This study compares 2D and 3D representations of in-building environments for visualization and mission rehearsal. In this experiment, two adjoining instrumented row house buildings (C4A and C4B) on the McKenna MOUT site at Ft Benning, GA, were used. Two representations of the buildings were used in the study: a 2D floor plan and a 3D virtual representation created using Half-Life computer software. Thirty-six regular force infantry soldiers participated in the study. Twelve soldiers were assigned to use the floor plan to learn a mission within the buildings and twelve were assigned to learn the same mission using the 3D virtual environment. The remaining twelve soldiers received only a verbal description of the mission, with no visual representation of the buildings. Following a mission rehearsal session with their respective visualization condition, soldiers completed their mission in the actual buildings. Each soldier completed the experiment first at night and then again the following day using a different route through the buildings.

In the course of experimentation, qualitative data was gathered in the form of pre-mission and post-mission questionnaires, comments and focus groups. Mission performance measures included visualization time, route time, route distance, terrain reconstruction drawings and bearing estimation errors to critical mission features.

Overall, qualitative results indicated that the floor plan and virtual environment were both better than no aid at all. Quantitative results show that performance for the floor plan group was better than the virtual environment group for time required for pre-mission visualization, bearing estimations to the mission objective at night and all aspects relating to the terrain reconstruction. There were no measures, qualitative or quantitative, where performance using the VE was significantly better than performance with the floor plan. So while there was utility in providing soldiers with terrain visualization capabilities for in-building operations, the plan view perspective of the 2D floor plan proved more effective than the immersive 3D virtual perspective.

Several information requirements were identified as vital to the development of a mental model, regardless of the visualization method. These include:

- Staircase locations (i.e. top and bottom)
- Room information (i.e. function, contents, mouse holes, windows)
- Door information (i.e. number, swing)
- Interior room layouts (size and number)
- Scale and distances
- Directional information (i.e. North)
- Overhead view of floor plan

Additional information that was desirable included:

- Type of building (i.e. residential or commercial)
- Construction of walls and structural integrity (i.e. brick or drywall)
- Enemy information (i.e. location, strength, size, morale and activity)

The interface design of any future visualization tool should include these features. None of the visualization conditions that were tested adequately satisfied these requirements, suggesting a number of opportunities for improvement or development for visualization tools in general.

While the 2D Floor Plan was the tool of choice for acquiring survey knowledge of in-building environments, soldiers suggested that the virtual environment tool still offered a useful, enriching source of visualization information. Further work suggested by this experiment includes investigations of different levels of rendering fidelity in the virtual environments and the development of a hybrid visualization tool that combines the best features of the 2D and 3D visualization aids (eg. a virtual environment tool that can also display a floor plan perspective).

Sommaire

La présente étude compare des représentations 2D et 3D d'environnements intérieurs de bâtiments pour les visualiser et se préparer à des missions. Au cours de cette expérience, on a utilisé deux maisons en rangée équipées d'instruments (C4A et C4B) sur le site McKenna MOUT à Fort Benning (GA). Deux représentations des bâtiments ont été utilisées au cours de l'étude : un plan d'étage 2D et une représentation virtuelle 3D créée avec le logiciel Half-Life. Trente-six soldats de la force régulière ont participé à l'étude. On a demandé à douze soldats d'utiliser un plan d'étage pour apprendre une mission à l'intérieur des bâtiments et à douze autres d'apprendre la même mission à l'aide d'un environnement virtuel 3D. Les douze derniers soldats n'ont reçu qu'une description orale de la mission, sans représentation visuelle des bâtiments. Après une répétition de la mission avec plan de visualisation, les soldats ont accompli leur mission dans les bâtiments. Chaque soldat a effectué l'expérience une première fois la nuit, puis une seconde fois le jour suivant, en suivant un parcours différent dans les bâtiments.

Au cours de cette expérience, des observations qualitatives ont été recueillies sous forme de questionnaires de préparation à la mission et de compte rendu de mission, de commentaires et de groupes de discussion. Les mesures de la performance en cours de mission, y compris le temps de visualisation, le temps de parcours, la distance de parcours, les dessins de reconstitution du terrain et les erreurs d'estimation de la position par rapport aux points de repère critiques à la mission, ont aussi été recueillies.

En général, les observations qualitatives ont indiqué que le plan d'étage et l'environnement virtuel sont tous les deux plus utiles qu'aucune aide. Elles ont aussi révélé que la performance du groupe qui avait étudié le plan d'étage était supérieure en termes de temps nécessaire à la visualisation de préparation à la mission, d'estimation des directions pour atteindre l'objectif la nuit et de tous les aspects ayant trait à la reconstitution du terrain. Aucune mesure qualitative ou quantitative de la performance du groupe ayant étudié l'environnement virtuel n'était nettement supérieure à la performance du groupe qui avait étudié le plan d'étage.

Plusieurs besoins en information ont été identifiés comme étant essentiels à la conception d'un modèle mental, peu importe la méthode de visualisation, par exemple :

- Emplacement des escaliers (c.-à-d. haut et bas)
- Information sur les pièces (c.-à-d. fonction, contenu, trous de communication, fenêtres)
- Information sur les portes (c.-à-d. numéro, sens d'ouverture)
- Aménagement intérieur des pièces (dimension et numéro)
- Échelle et distances
- Information directionnelle (nord)
- Plan d'étage vu du haut

Autre information utile :

- Type de bâtiment (c.-à-d. résidentiel ou commercial)
- Construction des murs et intégrité structurale (c.-à-d. brique ou cloisons sèches)
- Information sur l'ennemi (c.-à-d. emplacement, force, nombre, moral et activités)

La conception d'une interface d'un outil de visualisation devrait inclure ces besoins. Aucune méthode de visualisation éprouvée ne convenait à ces besoins, ce qui semble indiquer qu'il y a de nombreuses améliorations à apporter aux outils de visualisation en général.

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1. Background

Typically, soldiers procedurally perform map reconnaissance to develop and internalize a mental model of the terrain and their intended route prior to undertaking the tactical execution of a mission. This mental model is consulted during planning and decision-making to derive the most effective courses of action prior to and during a mission. For missions carried out inside buildings, soldiers are usually provided with no building information and must therefore rely on their experience of buildings in general to form their expectations and mental models of any new building (e.g. two storey residential likely has kitchen on first floor, one of two or three possible stairway configurations, etc.).

This experiment investigated the effect of providing 2D and 3D representations of an in-building environment for visualization and mission rehearsal. These visualization methods have been investigated and compared in the literature. Both have demonstrated different strengths and weaknesses in various experimental applications, although very few of these studies included an army context.

Several studies investigated the quality of navigation knowledge acquired from training using 2D maps compared to other navigation methods. Thorndyke and Hayes-Roth (1982) found that, with moderate exposure, map learning was effective for improving performance in straight-line distance estimations and relative location estimations. On the other hand, map training showed an orientation effect (Richardson, 1999; Tlauka and Wilson, 1996). Participants had difficulty if placed in the real environment in a different orientation from the orientation in which they originally learned the map.

The relative benefits of navigation training in a Virtual Environment (VE) have received a lot of recent attention in the literature. Studies by Christou and Bueltoff (1999), Wilson (1999), Witmer and Sadowski (1998), Tlauka and Wilson (1996), Satalich (1995) and Sebrechts (2000) have all used a “flythrough” perspective in a virtual environment. “Flythrough” refers to an active discovery in which the person flies over the terrain to acquire an overhead view, orient themselves to various headings, view the environment in perspective from different orientations, and then lowering to ground level to fly through the streets. The issue of transferability of training in a virtual environment to the real world has been examined with varying results. Richardson et al (1999) and Darken and Goerger (1999) both found problems with disorientation when training was conducted in a VE. Another problem with VE training was the underestimation of distances, which transfers into the real world when training is originally conducted in a VE (Witmer and Sadowski, 1998). Witmer et al (1996) found that VE training was not as effective as real-world training for route knowledge, but better than other conventional terrain visualization methods. Kozak et al (1993) and Clawson (1998) demonstrated that the VE was not as effective as training in the real environment for in-building navigation.

VE training was found by Richardson (1999) to be an effective training tool for the layout of landmarks on a single floor in a building. However, participants became disoriented when navigating multiple floors. Similarly, Wilson et al. (1997) found good performance on map drawing accuracy and orientation tasks (pointing to non-visible objects) after training in a VE. Several studies (Darken and Sibert 1996, Darken and Banker 1998, Goerger et al 1998, Darken and Goerger 1999) have been conducted as part of the Ground Reconnaissance of Urban and

Natural Terrain (GRUNT) experiments by the NPSNET Research Group at the Naval Postgraduate School. These experiments have examined the use of VE's as aids for route planning, rehearsal and navigation. Their findings support the use of maps or other conventional navigational aids over the VE's. However, they suggest that the benefits of VE use need further exploration.

Military research in the area of terrain visualization has focused largely on the use of virtual environments compared to traditional methods (e.g. maps or sand models) for decision support at the commander level. The focus has been on large-scale mission planning. There has been little research on the usefulness of virtual environments compared to other terrain visualization tools for small-scale navigation at the small unit and individual soldier level.

Infantry soldiers are required to conduct in-building operations in all lighting conditions. There has been limited research on navigation in degraded conditions. Tate et al (2000) investigated the use of a VE for shipboard firefighters and found that visibility in both the virtual training environment and the real world environment was degraded using simulated smoke. Unfortunately, they did not compare VE training performance in both degraded and non-degraded conditions.

While navigating, a soldier must focus on a goal-oriented mission and must be constantly searching for, and aware of, enemy and friendly forces. Most studies in the literature only require the primary task of navigation. Of these, most navigation research has focused on in-building environments in a non-military context (e.g. Thorndyke and Hayes-Roth 1982; Witmer et. al., 1996; Richardson et. al., 1999; Wilson et. al., 1997; Christou and Bueltoff, 1999).

The ability to adapt a mission plan and develop an alternative route plan, based on changes in mission conditions or on new information, is critical in dismounted infantry applications. However, only a few authors have examined the mission adaptability of different visualization methods. Satalich (1995) investigated how participants rearranged their route when they encountered a wall of fire while navigating a virtual building. Boer and Hirase (2000) measured participants' ability to develop shortcuts in a virtual world. Both of these studies were conducted entirely in a virtual environment and did not involve mission adaptation and transference to the real world environment. Grant and Magee (1998) investigated the suitability of different visualization methods for navigation in a real world environment and reported that training in VE, with a walking interface device, resulted in performance improvement for finding objects in the real environment.

In summary, the literature has investigated the effectiveness of several different visualization methods in non-military applications and has developed a number of objective measures for evaluating alternative visualization methods. The findings in the literature, comparing conventional and virtual visualization methods, are inconsistent, likely owing to the differences in focus, methodology, and terrain application. From the context of small unit dismounted infantry operations, the literature also tends to be weak in a number of areas: infantry mission applications, nighttime environments, in-situ adaptation to an unforeseen change in a mission plan, and secondary tasks during the mission (e.g. target detection and engagement). Therefore, the applicability of these studies to an infantry context is unclear. This experiment investigated the effectiveness of different conventional and virtual visualization capabilities for use in dismounted infantry missions for in-building terrain environments. The results of this experiment are related to the findings in the literature and are used to focus future development and experimentation.

2. Aim

The following aims were pursued in this experiment.

- Investigate the utility of providing soldiers with alternative terrain visualization capabilities for the purpose of urban in-building navigation.
- Evaluate the effectiveness and usability of alternative visualization methods.
- Identify interface design aspects critical to optimize display design in the visualization methods.

3. Method

This section describes the design of the experiment, the equipment and facilities used, the trial participants, experimental procedures and data collection methods used.

3.1 Design of Experiment

The experimental design included a two-factor (visualization method and night/day) analysis of variance with repeated measures on the second factor (night/day). Twelve soldiers were assigned to each of three experimental conditions (a total of 36 different soldiers) and each soldier completed the experiment twice – first at night and then again during the day.

3.2 Equipment/Facilities Used

3.2.1 McKenna MOUT Site and Buildings

The in-building visualization experiment was conducted in two buildings in the McKenna MOUT (Military Operations in Urban Terrain) site at Fort Benning, Georgia (see Figure 1).

(a) McKenna **(b) C4A and C4B**

Figure 1: Building C4A and C4B at the McKenna MOUT site, Fort Benning, Georgia

The buildings used were adjoining row houses at the south end of the McKenna village. Each building has two floors and a passageway on the second floor connecting the two buildings. There are staircases in both buildings: a single staircase in C4A and a double staircase with a landing in C4B. Both buildings have a single front door entrance on the west side of the building.

3.2.2 Visualization Aids

Each soldier was given one visualization aid to use during both night and day conditions. Visualization conditions included a No Aid condition, a 2D Floor Plan, and a Virtual Environment tool.

3.2.2.1 No Aid (Verbal Description)

As a baseline condition typical of current operations, soldiers were given a verbal description of the mission to be completed, along with a basic sketch drawn by the experimenter. The sketch only included an outline of the buildings' outermost walls and indicated the planned entry location, objective location, and North heading. No additional visualization information was given. The sketch and verbal description are described in more detail in Section 3.4.

3.2.2.2 2D Floor Plan

Soldiers were given a verbal description of the mission to be completed, along with a basic sketch drawn by the experimenter. The sketch indicated the planned entry location, objective location and North heading. In the 2D Floor Plan condition, soldiers used the floor plan in Figure 2 to aid visualization of the buildings. The floor plan showed all windows, doors, rooms, hallways, and stairs in a scale two-dimensional diagram. The scale of the diagram was not provided to soldiers in the experiment.

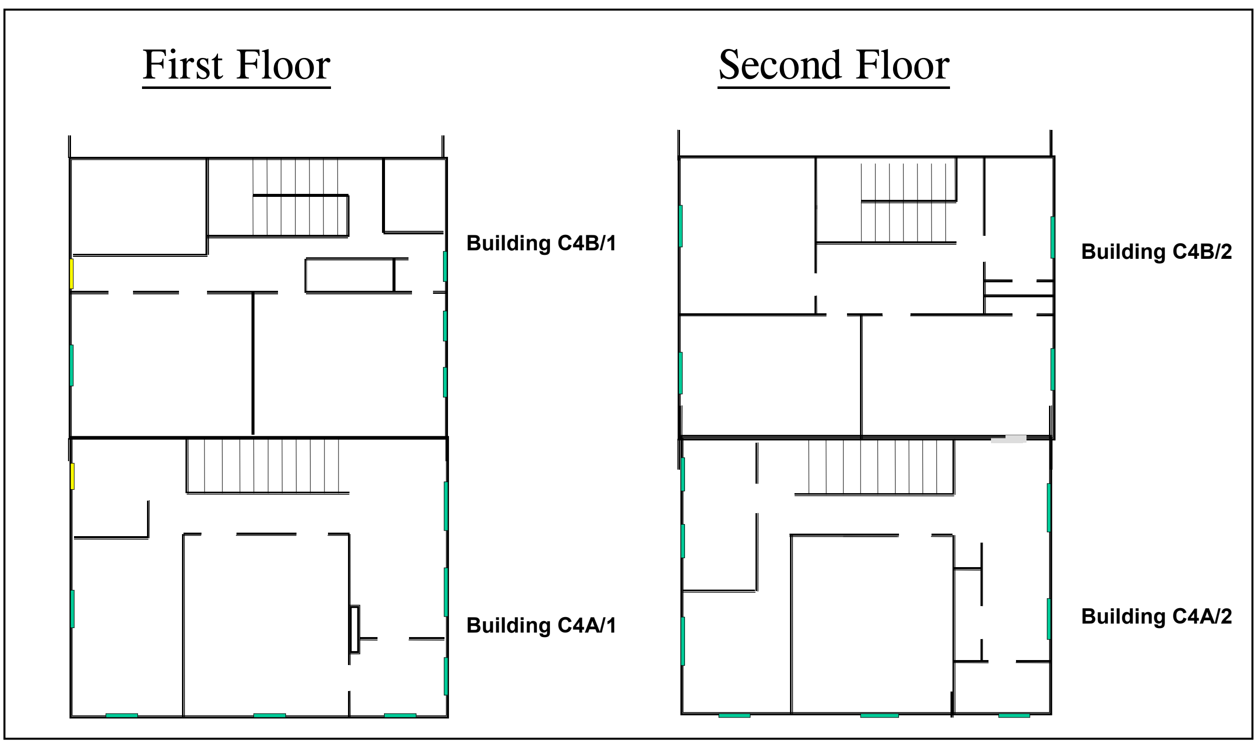


Figure 2: The 2D Floor Plan

3.2.2.3 Virtual Environment

Soldiers were given a verbal description of the mission to be completed, along with a basic sketch drawn by the experimenter. The sketch indicated the planned entry location, objective location and North heading. The virtual representation of the buildings used in this experiment was created in Worldcraft software and used with the Half-life gaming engine. Half-life is a first-person gaming software where players can virtually navigate buildings using mouse and keyboard controls. The VE was highly detailed, showing all doors, windows, fixtures, and furniture in the buildings used. A screenshot from the experimental VE is shown next to a photograph of the actual room in Figure 3 below.

(a) Virtual Environment **(b) Actual room**

Figure 3: Comparison of virtual and real terrain

3.2.3 Night Vision Goggles

During the night condition, soldiers wore AN/PVS-504A Night Vision Goggles (NVG's). The goggle assembly is a head-mounted self-contained night vision system containing one biocular unit consisting of an objective lens assembly, an image intensifier tube, a housing assembly, and a binocular eyepiece assembly (see Figure 4).

Figure 4: AN/PVS-504A

3.3 Trial Participants

Thirty-six regular force infantry soldiers were recruited from the 3rd Battalion PPCLI Regiment, CFB Edmonton. Soldiers were assigned to one of the three visualization methods (No Aid, 2D Floor Plan or VE). Each visualization method was used by 12 soldiers. Before the experiment began, soldiers completed personal information questionnaires and were given spatial ability tests. The trial took place from 08 – 12 March 2001.

3.4 Procedures

Soldiers were brought individually to the mission briefing area in a separate building on the McKenna site. While being transported to the mission briefing area, they wore darkened goggles in order to prevent any learning about the target buildings during transportation. In the mission briefing area, the soldiers were given the following briefing and shown the sketch in Figure 5 below:

> "Your mission will be to gain entry to the building through the door indicated in the first building and make your way to the second floor where you will find an entranceway to the second building (* Show sketch *). You will make your way down to the first floor of the second building and find the target objective in the Southwest corner of the Southwest room on the first floor. The objective will be an important document, and the mission will end once you touch this document. Anticipate that you may or may not be required to adapt to unforeseen changes in the situation, but the objective will remain the same. Enroute you may encounter enemy soldier targets (* Show target *). You are required to engage these targets with your personal weapon by firing two rounds into the target. You will also be stopped during the route and be asked to indicate where you think your entrance and objective location are relative to your position. The timing will be paused during this process and you will be asked to use a digital compass, holding it level while pointing it at the perceived locations. (* Show how to use electronic compass *) You will be evaluated on your ability to navigate your route, the time required for you to detect targets and your ability to engage these targets."

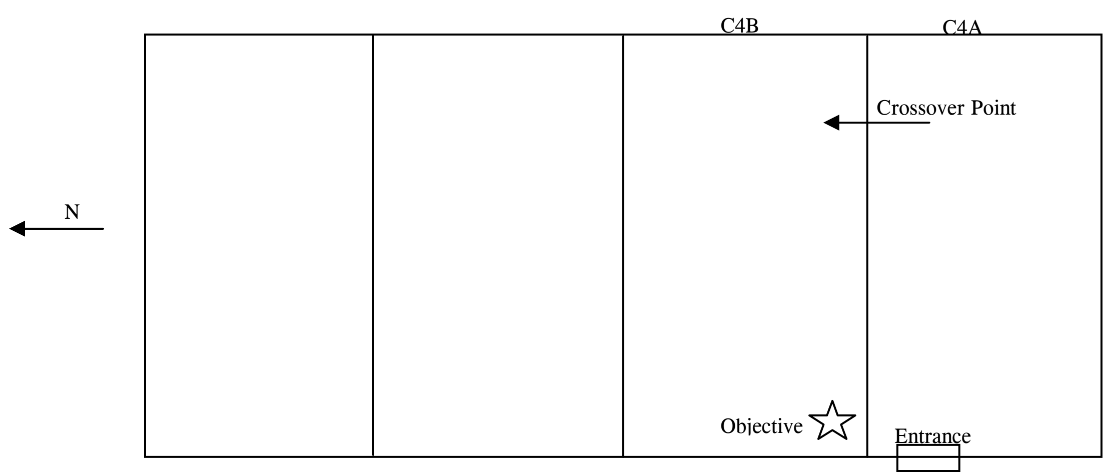


Figure 5: Mission explanation sketch

Once briefed on the mission, the soldier was given his assigned visualization aid. If the soldier was in the No Aid condition, he did not complete this part of the experiment. Those soldiers in the other two conditions were instructed to study the building using the assigned aid until each soldier felt confident that he had acquired sufficient knowledge to carry out the mission. Soldiers were given the following briefing:

> "Use this information to visualize the environment and your mission. Study the buildings until you feel confident that you have acquired sufficient knowledge to carry out the mission."

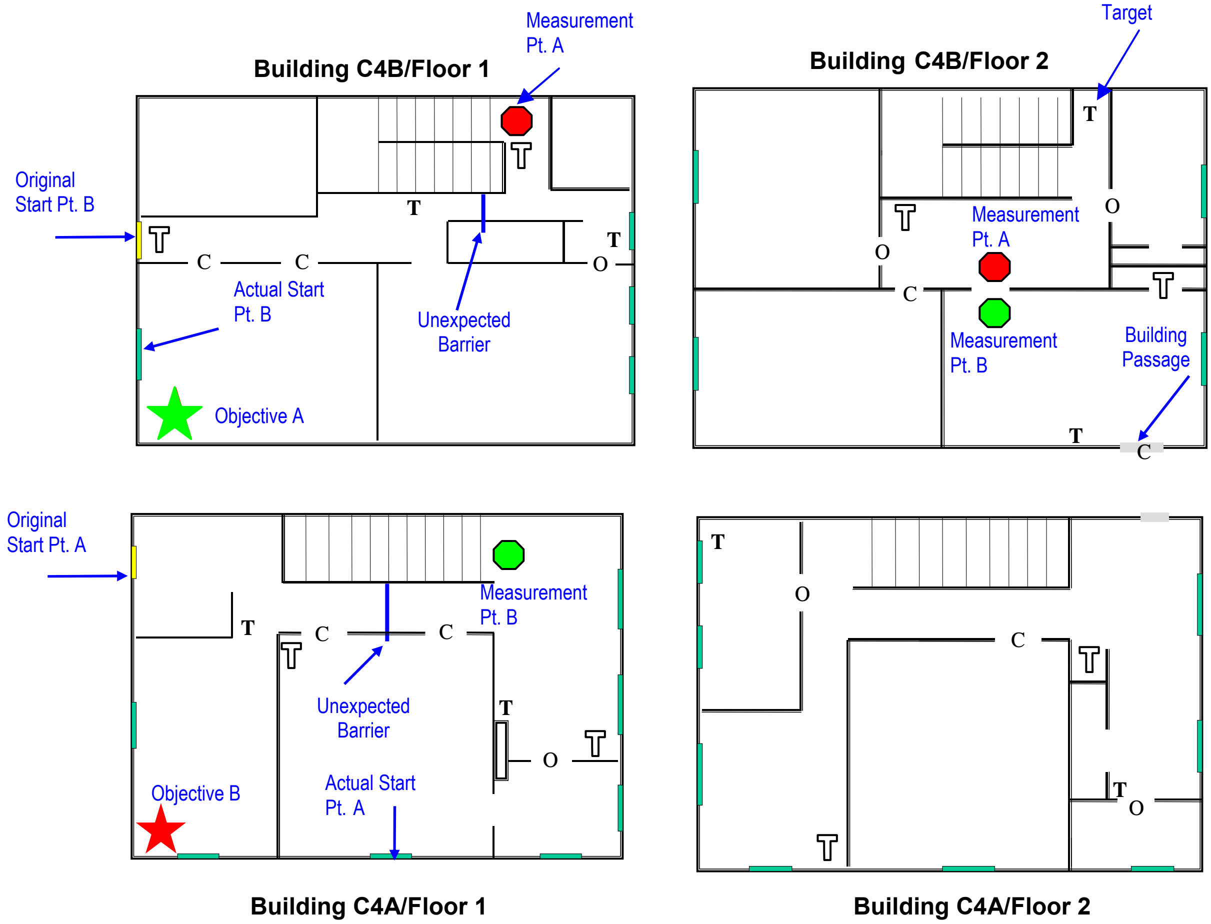
A maximum of 20 minutes was allowed for pre-mission visualization.

Following the visualization session, the visualization aid was removed and the soldier was required to draw a two-dimensional reconstruction of the building on scaled grid paper. Soldiers were told that their drawings would be scored on accuracy, scale and relative positioning of structures. The mission briefing went as follows:

> "Draw a 2-dimensional reconstruction of the buildings on a scaled grid paper. Draw all rooms, stairs, furnishings and hallways in as accurate a scaled diagram as possible and indicate the direction of North. Indicate your route plan and the location of the target objective in the adjoining building. The drawings will be scored on accuracy, scale, and relative positioning of rooms and furnishings.

Once the soldier had finished his terrain reconstruction, he completed a pre-mission questionnaire.

The experimenter then took the soldier to the start point of his mission (the front door of either building A or building B). At the start point, the soldier was instructed that the front door was blocked and he would have to adapt his mission by entering the building through a side window as shown in Figure 6. Soldiers were reminded that enemy soldier targets must be detected and engaged en-route to the objective location. The soldiers were also reminded that they would be stopped at various points during the route and asked to indicate the entry (start) location and the objective location. The experimenter brought the soldier to the window to begin the mission. At this point, the experimenter radioed the control room to request data collection for the soldier run. On the experimenter's signal, the control room began position, video, and time recording, and the soldier began to execute the mission.



T : Route A Targets		O: Open Door
Ͳ : Route B Targets		C: Closed Door

Figure 6: Building C4A and C4B experimental layout

For each mission route, an unexpected barrier was placed on the mission path (see Figure 7). The location of the barriers is shown in Figure 6. When the soldier encountered this barrier, he was required to adapt to this barrier by changing his route through the buildings.

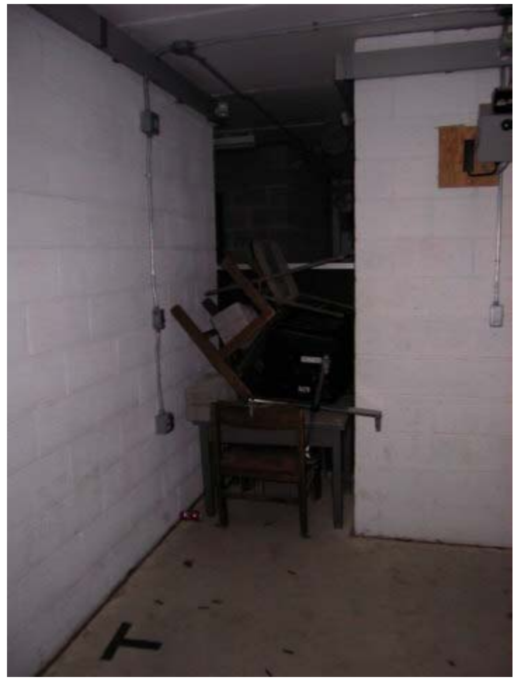


Figure 7: Unexpected barrier

To simulate the tactical demands of operational movement through a building environment and to provide a distraction from sole concentration on the building layout, eight Carswell targets were positioned at critical points in the building to simulate enemy soldiers (see Figure 8). The targets were arranged differently for each route as shown in Figure 6. While navigating the building, soldiers were required to detect and engage these targets with their personal weapons.

Figure 8: Carswell targets

During navigation through the building, the experimenter stopped soldiers at two pre-selected measurement points (see Figure 6). At each measurement point, the soldier was required to hold an electronic compass and point to each of two mission reference points, the start point and the objective (See Figure 9). The experimenter recorded the bearing from the electronic compass as the soldier pointed to each reference point.

Figure 9: Measurement point

The positional track of each soldier's movement through the building was captured by the OTVIS tracking system in the McKenna control room (see Figure 10). A video recording of the soldiers' movements was also taken.

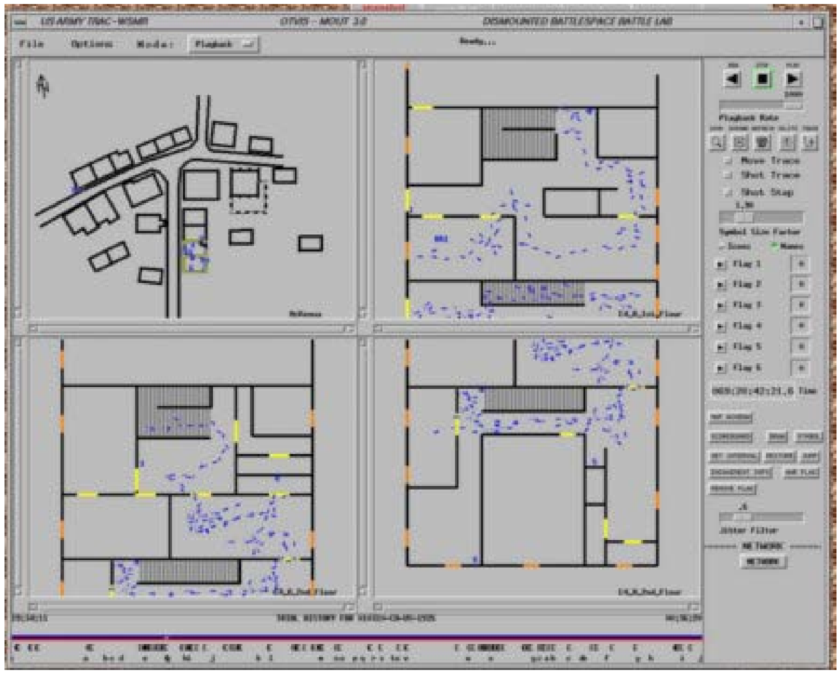


Figure 10: OTVIS Track (captured in McKenna control room)

When the soldier believed he had reached the objective, he indicated this to the experimenter (see Figure 11). The experimenter radioed the control room to indicate that the experiment was complete, and thus position tracking and video capture could be terminated.

Figure 11: Reaching the objective

The experimenter then returned to the mission briefing area with the soldier where the soldier completed the post-mission questionnaire. The soldier was instructed not to discuss the buildings or the experiment with others.

Each soldier completed the experiment twice; first at night, and then again the following day. In each case, the soldier performed the night session prior to the day session to minimize any learning effects from one session to another. As well, soldiers were given a different mission, different objective, and different direction of travel through the buildings between night and day sessions.

3.5 Data Collection Methods – Qualitative Measures

3.5.1 Spatial Ability Tests

Three timed cognitive ability tests from the *Kit of Factor-Referenced Cognitive Tests* were administered to all soldiers prior to experimentation (Ekstrom et. al, 1976). The tests were conducted and scored according to the procedures described in the Manual for The Kit of Factor Referenced Cognitive Tests. The tests used were:

1. Map Planning Test
2. Building Memory Test
3. Map Memory Test

The Map Planning Test, Building Memory Test and Map Memory Test tested spatial scanning and visual memory skills applicable to the Visualization experiment.

3.5.2 Personal Information Questionnaire

Before the experiment began, soldiers completed a personal information questionnaire (see Annex A) rating their skills, experience and abilities in applicable areas.

Soldiers rated their skills in the following areas:

- Planning Skills
- Rehearsal Skills
- Map Reading Skills
- Sense of Direction
- Ability to Use NVG's

Soldiers rated their experience in the following areas:

- Training and/or operational experience planning missions
- Training and/or operational experience conducting task rehearsals
- Training and/or operational experience using maps
- Training and/or operational experience in urban operations
- Experience using 1st person computer games

3.5.3 Questionnaires

In the course of experimentation, soldiers completed two questionnaires: a pre-mission questionnaire (see Annex B) and a post-mission questionnaire (see Annex C). For both questionnaires, soldiers used the seven-point acceptability scale in Figure 12 to rate the acceptability of various criteria with respect to the visualization method used.

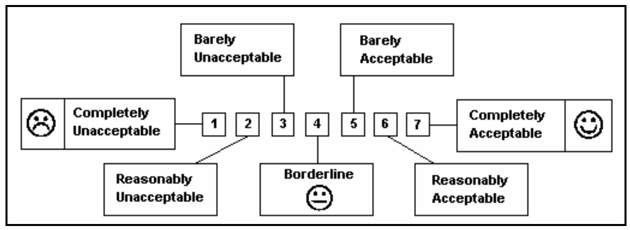


Figure 12: The seven-point acceptability scale

3.5.3.1 Pre-mission Questionnaires

Pre-mission questionnaires were administered after the soldiers had completed their mission rehearsal with their assigned visualization aid, but before they entered the building. The pre-mission questionnaire asked the soldiers to rate the following:

- **Effectiveness of Method for:**
  - Route planning
  - Awareness of building layout
  - Accuracy of building knowledge
  - Completeness of building knowledge
  - Awareness of mission features
- **Confidence in Method for:**
  - Planning route
  - Navigating building
- **Mental Workload of Method:**
  - Time pressure during visualization
  - Complexity of information
  - Ease of interpreting information
  - Ease of creating mental image of village
  - Ease of estimating distances
- **General:**
  - Contribution to in-building awareness
  - Ease of acquiring visualization knowledge
  - Mental workload to use knowledge
  - Time required to use method
  - Ease of using method
  - Confidence in visualization knowledge
- **Overall Acceptability of Method**
  - Overall acceptance

3.5.3.2 Post-mission Questionnaires

At the completion of the exercise, soldiers completed post-mission questionnaires. The post-mission questionnaire asked the soldiers to rate the following:

- **Effectiveness of Method for:**
  - Route planning
  - Changing a mission route on the fly
  - Awareness of buildings
  - Awareness of own location
  - Awareness of objective location
- **Mental Workload of Method:**
  - Ease of planning route
  - Ease of navigating in-building
  - Ease of detecting targets
  - Ease of relating real buildings to visualization method
  - Ease of estimating distance
  - Time pressure during navigation
  - Ease of estimating locations
- **General:**
  - Contribution to in-building awareness
  - Ease of acquiring visualization knowledge
  - Mental workload to use knowledge
  - Confidence in visualization knowledge
- **Overall Acceptability of Method**
  - Overall acceptance

3.5.3.3 Focus Group

At the conclusion of the experiment, all soldiers participated in a focus group. The focus group was led by an experimenter and took the form of a structured discussion on the positive and negative aspects of the different visualization aids.

3.6 Data Collection Methods – Quantitative Measures

Soldiers completed the experimental sessions one at time. Throughout the full experiment, each soldier was accompanied by an experimenter. The experimenter supervised the pre-mission preparation and visualization session as well as followed the soldier as he navigated the buildings in order to collect data. The following quantitative data were collected.

3.6.1 Visualization Time

The time the soldier took to learn the environment, using a visualization aid, was recorded by the experimenter. A maximum of 20 minutes was allowed.

3.6.2 Route Time

The time to complete the mission from when the soldier entered the building and was instructed to begin, to when the soldier indicated he had reached the objective was recorded in the McKenna control room. The time elapsed during data collection at measurement points was subtracted from the route times.

3.6.3 Terrain Reconstruction

The map reconstructions drawn by the soldiers after their visualization session were scored according to the following criteria:

- Orientation: 1 point possible
  - 1 point: Correctly indicating North on the reconstruction.
- Landmark Knowledge: 5 points possible
  - 1 point: Building crossover indicated correctly.
  - 1 point: Location of building A stairs correct.
  - 1 point: Type of stairs in building A correct.
  - 1 point: Location of building B stairs correct.
  - 1 point: Type of stairs in building B correct.
- Room Knowledge (Survey Knowledge): 27 points possible
  - 27 points: Total number of rooms.
- Room Knowledge (Route Knowledge): 10 points possible
  - 10 points: Total number of rooms on route.
- Mission Knowledge: 5 points possible
  - 1 point: Entrance indicated correctly.
  - 1 point: Objective indicated correctly.
  - 3 points: Number of enroute doors indicated correctly.
- Reconstruction of Buildings: 3 points possible (discretion of marker)
  - 1 point: Drawing not similar to buildings at all.
  - 2 points: Drawing is somewhat similar to buildings.
  - 3 points: Drawing is extremely similar to buildings.

3.6.4 Bearing Estimates

The difference between the actual bearing and bearing given at each of the measurement points was recorded.

3.6.5 Route Information

The distance of the route taken was determined from the OTVIS track. This distance was compared to the optimum route (the shortest route to the objective).

4. Results and Discussion

The results of data gathered during the in-building visualization experiment are presented in the following section. The results were analyzed using an analysis of variance between visualization conditions and differences were identified using a post-hoc Duncan test. For each set of results, significant differences are noted at $p<0.05$ and $p<0.10$. The results are discussed immediately after they are presented. For all measures, missing data were replaced by means according to the visualization method used, time of day and where appropriate, the route taken through the buildings. This will be indicated where necessary.

4.1 Qualitative Results

4.1.1 Personal Information

Before participating in the experiment, soldiers completed questionnaires on their skills and experience. No significant differences were found between the self-reporting of visualization groups in either skills or experience. The results of these questionnaires are tabulated in Tables 1 and 2 below.

	Visualization Method			Significant Differences p<.05
	1. No Aids (n=12)	2. Floor Plan (n=12)	3. VE (n=12)	
Planning	3.9 ± 0.7	3.5 ± 0.5	3.5 ± 0.8	None
Rehearsal	3.9 ± 0.5	3.6 ± 0.8	3.6 ± 0.7	None
Map Reading	3.8 ± 0.8	4.0 ± 0.9	3.8 ± 0.8	None
Sense of Direction	3.7 ± 0.7	3.7 ± 1.0	3.8 ± 0.8	None
Ability to Use NVG’s	3.7 ± 0.7	3.8 ± 0.6	3.7 ± 0.6	None

Table 1: Results of skills questionnaire

On average, soldiers in all three visualization groups rated their skills at planning, rehearsal, map reading, sense of direction and ability to use NVG’s as fair (3) to good (4).

	Visualization Method			Significant Differences p<.05
	1. No Aids (n=12)	2. Floor Plan (n=12)	3. VE (n=12)	
Planning Missions	2.5 ± 1.0	2.2 ± 0.7	2.1 ± 0.9	None
Conducting Task Rehearsals	2.8 ± 1.0	2.6 ± 0.5	3.1 ± 0.9	None
Using Maps	3.0 ± 0.7	2.9 ± 0.7	2.9 ± 0.9	None
Urban Operations	2.4 ± 0.7	2.3 ± 0.5	2.3 ± 0.5	None
Using 1st Person Computer Games	2.2 ± 1.0	2.2 ± 0.7	2.6 ± 1.1	None

Table 2: Results of experience questionnaire

On average, soldiers in all three visualization groups reported having between some (2) to moderate (3) experience at planning missions, conducting task rehearsals, using maps, urban operations, and using 1st person computer games.

4.1.2 Cognitive Ability Tests

The results of three cognitive ability tests were analyzed according to visualization groups to see if there were any differences between groups.

The three tests conducted were:

- Building Memory Test
- Map Memory Test
- Map Planning Test

The results of the cognitive ability tests by visualization group are tabulated below.

	Visualization Method			Significant Differences p<.05
	1. No Aids (n=12)	2. Floor Plan (n=12)	3. VE (n=12)	
Building Memory (visual memory)	.42 ± 0.2	.66 ± 0.3	.58 ± 0.3	2>1
Map Memory (visual memory)	.63 ± 0.2	.81 ± 0.2	.85 ± 0.1	2,3>1
Map Planning (spatial planning)	.51 ± 0.1	.60 ± 0.2	.54 ± 0.1	None

Table 3: Cognitive ability test results

There were no significant statistical differences between visualization groups in performance on the Map Planning test. However, there were differences in Building Memory and Map Memory test performance. In the former, soldiers in the Floor Plan group performed significantly better than those in the No Aid group. In the latter, soldiers in both the Floor Plan and VE conditions outperformed those in the No Aid group.

These results suggest that differences between the No Aid group and the other groups may be partially attributable to differences in cognitive ability between groups.

4.1.3 Pre-mission Questionnaire

Soldiers completed pre-mission questionnaires after their visualization session but before completing their navigation of the building. The questions were rated using the seven-point acceptability scale. The results are tabulated separately for night and day below. Mean acceptance ratings of less than 4.0 indicated “Unacceptable” ratings and have been highlighted with shading in the tables. (Missing data includes 22 out of 1368).

	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Effectiveness of Method for:				
Route Planning	3.8 ± 2.1	5.3 ± 0.9	4.8 ± 1.8	2>1
Awareness of Building Layout	2.8 ± 1.8	4.9 ± 1.0	4.6 ± 1.7	2,3>1
Accuracy of Building Knowledge	2.4 ± 1.6	4.3 ± 1.4	4.9 ± 1.6	2,3>1
Completeness of Building Knowledge	2.0 ± 1.5	4.3 ± 1.4	4.7 ± 1.8	2,3>1
Awareness of Mission Features	3.0 ± 1.9	4.7 ± 1.4	5.6 ± 1.0	2,3>1
Confidence in Method for:				
Planning Route	3.5 ± 1.9	5.2 ± 0.8	4.6 ± 1.8	2>1
Navigating Building	3.5 ± 2.0	5.1 ± 0.9	4.4 ± 1.8	2>1
Mental Workload of Method:				
Time Pressure During Navigation	5.0 ± 2.0	4.9 ± 1.9	4.3 ± 1.7	None
Complexity of Information	4.2 ± 2.3	5.3 ± 1.2	4.3 ± 2.0	None
Ease of Interpreting Information	5.9 ± 1.2	5.5 ± 1.5	4.6 ± 1.9	None
Ease of Creating Mental Image of Building	3.8 ± 2.1	5.5 ± 1.2	4.6 ± 1.9	2>1
Ease of Estimating Distances	2.4 ± 1.3	4.4 ± 1.4	3.9 ± 1.4	2,3>1
General:				
Contribution to In-Building Awareness	2.4 ± 1.4	4.6 ± 1.2	4.3 ± 1.8	2,3>1
Ease of Acquiring Visualization Knowledge	3.2 ± 1.6	4.5 ± 1.5	5.0 ± 1.8	3>1
Mental Workload to Use Knowledge	4.1 ± 2.0	4.6 ± 1.4	4.8 ± 1.6	None
Time Required to Use Method	5.6 ± 1.5	5.4 ± 1.2	3.6 ± 1.7	1,2>3
Ease of Using Method	5.3 ± 2.0	5.3 ± 1.4	5.3 ± 1.2	None
Confidence in Visualization Knowledge	3.0 ± 1.5	5.3 ± 1.1	4.6 ± 1.8	2,3>1
Overall:				
Overall Acceptability of Method	3.4 ± 1.2	4.9 ± 1.4	4.7 ± 1.5	2,3>1

Table 4: Means and standard deviations for nighttime pre-mission questionnaire

	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Effectiveness of Method for:				
Route Planning	3.2 ± 1.9	5.3 ± 1.6	5.3 ± 1.3	2,3>1
Awareness of Building Layout	2.9 ± 1.6	5.3 ± 1.1	5.7 ± 1.3	2,3>1
Accuracy of Building Knowledge	2.4 ± 1.2	4.9 ± 1.2	5.5 ± 1.2	2,3>1
Completeness of Building Knowledge	2.4 ± 1.2	4.3 ± 1.2	5.3 ± 1.3	2,3>1
Awareness of Mission Features	2.9 ± 1.6	5.2 ± 1.8	5.3 ± 1.1	2,3>1
Confidence in Method for:				
Planning Route	2.9 ± 1.6	5.7 ± 1.2	5.3 ± 1.4	2,3>1
Navigating Building	3.1 ± 1.6	5.3 ± 1.3	4.8 ± 1.9	2,3>1
Mental Workload of Method:				
Time Pressure During Navigation	4.9 ± 2.2	5.4 ± 1.2	5.3 ± 1.2	None
Complexity of Information	4.7 ± 2.6	5.5 ± 1.6	5.1 ± 1.4	None
Ease of Interpreting Information	5.7 ± 1.9	5.3 ± 1.9	5.3 ± 1.4	None
Ease of Creating Mental Image of Building	3.0 ± 2.1	5.1 ± 1.8	5.5 ± 1.0	2,3>1
Ease of Estimating Distances	2.9 ± 1.6	4.3 ± 1.5	3.8 ± 1.3	2>1
General:				
Contribution to In-Building Awareness	2.5 ± 1.0	4.8 ± 1.2	5.3 ± 1.1	2,3>1
Ease of Acquiring Visualization Knowledge	2.8 ± 1.5	5.2 ± 1.8	5.4 ± 1.5	2,3>1
Mental Workload to Use Knowledge	4.4 ± 2.3	5.3 ± 1.5	5.2 ± 1.2	None
Time Required to Use Method	5.8 ± 1.5	5.3 ± 1.4	5.6 ± 2.1	None
Ease of Using Method	5.7 ± 1.7	5.4 ± 1.6	5.9 ± 1.0	None
Confidence in Visualization Knowledge	3.0 ± 1.7	5.1 ± 1.5	5.3 ± 1.6	2,3>1
Overall:				
Overall Acceptability of Method	2.8 ± 1.5	5.0 ± 1.7	5.2 ± 0.7	2,3>1

Table 5: Means and standard deviations for daytime pre-mission questionnaire

The Floor Plan was rated acceptable on all of the pre-mission categories for both day and night. All the mean ratings for the Floor Plan exceeded "Borderline" (4) on the seven-point scale of acceptance. The VE condition too was rated acceptable on all of the categories except for ease of estimating distances, for both day and night, and the time required to use the method in the nighttime condition only. Comments reinforced soldiers' difficulty in visualizing distances using the VE.

On the other hand, the No Aid condition was rated unacceptable in many of the categories. Almost all of the average ratings for the No Aid method were below “borderline” (4), underscoring its unacceptability for visualizing the task. High acceptance ratings in the No Aid condition, however, were related to the fact that the limited amount of information was quick and easy to interpret and memorize.

In terms of effectiveness, the Floor Plan and VE were rated significantly better than the No Aid condition. The only exception was for route planning in the nighttime condition, where there was no significant effect between the No Aid and the VE visualization methods.

Regarding the confidence in the method, the Floor Plan was significantly more acceptable than No Aid in the nighttime condition. In the daytime condition, both the Floor Plan and VE were rated significantly more acceptable than No Aid.

Under mental workload of method, there was no significant difference between visualization methods for time pressure during navigation, complexity of information, and ease of interpreting information for night or day. However, the Floor Plan was rated significantly more acceptable than No Aid method for ease of creating a mental image of the building and ease of estimating distances for both day and night. VE was rated significantly more acceptable than No Aid for ease of creating a mental image of the building in the daytime condition and ease of estimating distances in the nighttime condition.

In the general category, the Floor Plan and the VE were rated significantly better than the No Aid condition for contribution to in-building awareness and confidence in visualization knowledge. With respect to ease of acquiring visualization knowledge, VE was significantly more acceptable than No Aid in both conditions; whereas, the Floor Plan was significantly more acceptable for the daytime condition only. In the nighttime condition, ratings revealed that the time required to use the method was significantly more acceptable for No Aid and Floor Plan over VE.

At night, soldiers rated the time required to use the VE as significantly less acceptable than the time required to use the Floor Plan and No Aid. In fact, soldiers’ average rating for VE under this criterion was less than “Borderline”, indicating that a majority of soldiers found the time required to use the VE method unacceptable. In the day condition, there were no differences between the three visualization aids for acceptance ratings of time required to use method, likely due to soldiers’ familiarity with the VE software program.

The familiarity with the VE tool may explain its improved acceptance over the No Aid method (route planning, planning route, navigating building and ease of creating mental image of building) in the daytime conditions.

In overall acceptability, both the Floor Plan and VE were significantly more acceptable than the No Aid condition, indicating that soldiers found having any information more useful than no information at all. Aside from the time required to use the method in the nighttime condition, there was a lack of significant differences between the Floor Plan and VE. The willingness of the soldiers to accept the VE indicates an overall positive attitude towards this visualization method.

4.1.4 Post-mission Questionnaire

When the mission was over, soldiers completed a post-mission questionnaire with regards to how their visualization method affected their mission. The results for this questionnaire are tabulated separately for day and night below. (Missing data includes 4 out of 1224).

	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Effectiveness of Method for:				
Route Planning	2.8 ± 1.9	5.3 ± 1.9	4.9 ± 1.4	2,3>1
Changing a Mission Route of the Fly	3.8 ± 2.3	5.8 ± 1.1	5.0 ± 1.7	2>1
Awareness of Buildings	3.6 ± 2.0	5.2 ± 2.1	5.1 ± 1.3	2,3>1
Awareness of Own Location	3.4 ± 2.4	5.7 ± 1.8	4.8 ± 1.6	2>1
Awareness of Objective Location	3.8 ± 2.3	6.1 ± 1.4	5.2 ± 1.7	2>1
Mental Workload of Method:				
Ease of Planning Route	3.3 ± 2.2	5.7 ± 1.4	4.8 ± 1.4	2,3>1
Ease of Navigating In-Building	2.8 ± 2.1	5.3 ± 1.9	4.6 ± 1.6	2,3>1
Ease of Detecting Targets	4.0 ± 2.3	5.8 ± 1.1	4.8 ± 1.8	2>1
Ease of Relating Real Building to Visualization Method	3.0 ± 2.0	5.6 ± 1.4	5.0 ± 1.5	2,3>1
Ease of Estimating Distance	2.8 ± 1.8	4.8 ± 1.8	3.8 ± 1.1	2>1
Time Pressure During Navigation	3.8 ± 1.9	5.7 ± 1.4	5.0 ± 1.0	2>1
Ease of Estimating Locations	3.8 ± 2.3	5.8 ± 1.4	4.8 ± 1.5	2>1
General:				
Contribution to In-Building Awareness	3.2 ± 1.6	5.3 ± 1.5	5.1 ± 1.5	2,3>1
Ease of Acquiring Visualization Knowledge	3.8 ± 1.9	5.3 ± 1.5	5.2 ± 1.3	2,3>1
Mental Workload to Use Knowledge	3.9 ± 2.0	5.4 ± 1.7	5.1 ± 1.3	2>1
Confidence in Visualization Knowledge	3.4 ± 1.6	5.3 ± 1.2	5.0 ± 1.7	2,3>1
Overall:				
Overall Acceptability of Method	3.2 ± 1.5	5.4 ± 1.7	5.2 ± 1.3	2,3>1

Table 6: Means and standard deviations for nighttime Post-mission Questionnaire

	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Effectiveness of Method for:				
Route Planning	3.0 ± 1.9	5.5 ± 1.9	5.8 ± 1.1	2,3>1
Changing a Mission Route of the Fly	4.3 ± 2.1	5.4 ± 1.8	5.8 ± 1.1	None
Awareness of Buildings	3.2 ± 1.9	5.1 ± 1.5	5.5 ± 1.2	2,3>1
Awareness of Own Location	4.2 ± 2.2	5.8 ± 1.1	5.7 ± 1.1	2,3>1
Awareness of Objective Location	3.9 ± 2.5	6.3 ± 0.8	5.7 ± 1.4	2,3>1
Mental Workload of Method:				
Ease of Planning Route	3.5 ± 2.0	5.8 ± 1.2	5.8 ± 0.8	2,3>1
Ease of Navigating In-Building	3.3 ± 2.1	5.5 ± 1.6	5.7 ± 0.8	2,3>1
Ease of Detecting Targets	4.7 ± 2.3	6.3 ± 0.8	5.8 ± 0.9	2>1
Ease of Relating Real Building to Visualization Method	3.8 ± 2.1	5.5 ± 1.1	5.5 ± 1.4	2,3>1
Ease of Estimating Distance	3.0 ± 1.6	5.0 ± 1.3	4.3 ± 1.7	2,3>1
Time Pressure During Navigation	4.3 ± 1.6	5.6 ± 1.3	5.5 ± 0.9	2,3>1
Ease of Estimating Locations	3.9 ± 1.9	5.8 ± 1.5	5.5 ± 1.1	2,3>1
General:				
Contribution to In-Building Awareness	3.4 ± 1.7	5.3 ± 1.5	5.4 ± 1.4	2,3>1
Ease of Acquiring Visualization Knowledge	4.0 ± 2.0	5.2 ± 1.6	5.6 ± 1.1	3>1
Mental Workload to Use Knowledge	4.5 ± 1.9	5.6 ± 1.3	5.5 ± 1.2	None
Confidence in Visualization Knowledge	3.8 ± 1.8	5.4 ± 1.4	5.6 ± 1.2	2,3>1
Overall:				
Overall Acceptability of Method	3.4 ± 1.7	5.3 ± 1.6	5.6 ± 1.0	2,3>1

Table 7: Means and standard deviations for daytime Post-mission Questionnaire

In the post-mission questionnaire, the Floor Plan was rated acceptable in all categories for both day and night. Outside the ease of estimating distances in the nighttime condition, the VE was rated acceptable for all categories. Consistent with pre-mission acceptability ratings, the No Aid condition was rated unacceptable in many categories in the nighttime and daytime condition.

Under effectiveness of the method, the Floor Plan was rated significantly more acceptable than No Aid for all criteria except changing a mission route on the fly in the day. At night, VE was rated significantly better than No Aid for route planning and awareness of buildings. However, in the day, VE was rated significantly better than No Aid on all effectiveness criteria other than changing a mission route on the fly.

Under mental workload, the Floor Plan was rated significantly more acceptable than No Aid for all criteria in both daytime and nighttime conditions. At night, the VE was rated significantly more acceptable than No Aid for ease of planning route, ease of navigating in-building, and ease of relating real building to visualization method. During the day, VE was rated significantly more acceptable than No Aid for all criteria under mental workload except ease of detecting target.

Interestingly, at night, the VE was rated unacceptable (mean<4) for ease of estimating distances, both pre-mission and post-mission, as well as pre-mission day. However, by post-mission day, the mean response in this category had risen to an acceptable range (mean>4). This may indicate that more experience with the VE tool improves the ability of participants to estimate distance or soldiers were better able to scale the VE model to the real environment following their experience in the nighttime condition.

With respect to the general category, the Floor Plan and VE were rated significantly more acceptable than No Aid for contribution to in-building awareness and confidence in visualization knowledge in both nighttime and daytime conditions. The VE was rated significantly more acceptable than No Aid for ease of acquiring visualization knowledge in both nighttime and daytime conditions; whereas, the Floor Plan was rated significantly more acceptable than No Aid only at night.

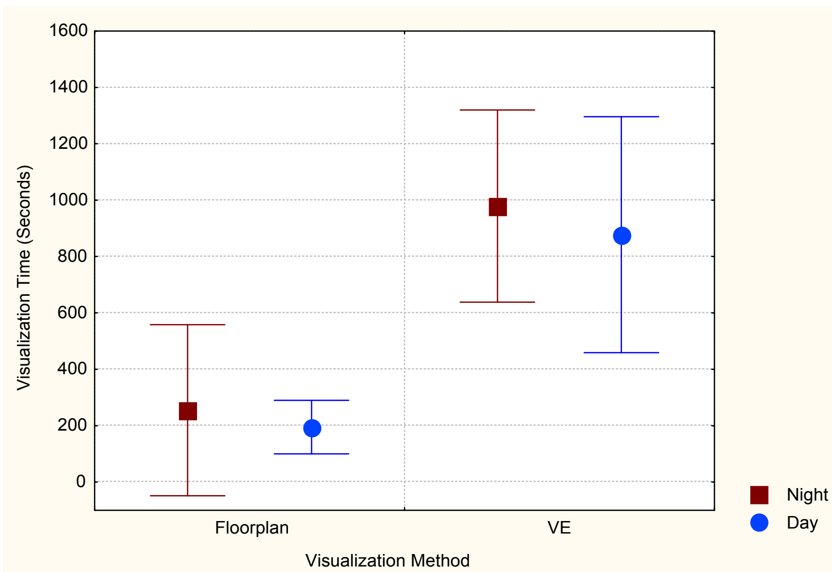
Again, there were no significant differences in the post-mission questionnaires between the Floor Plan and the VE condition, although in almost all questions both the VE and Floor Plan were rated more acceptable than the No Aid condition. The fact that opinions about the visualization aids changed little from pre-mission to post-mission likely indicates that soldiers were not surprised upon entering the actual buildings and were able to relate the visualization aid to the actual buildings.

Several non-significant trends appear in the post-mission questionnaire data. At night, the Floor Plan was ranked more acceptable than the two other conditions for all items. However, by the daytime condition, the VE visualization aid was rated more acceptable on seven items. These include route planning, changing a mission on the fly, awareness of buildings, ease of navigating in-building, contribution to in-building awareness, ease of acquiring visualization knowledge, and confidence in visualization knowledge. Thus, learning and prior experience may increase the usefulness of the VE, but not the Floor Plan.

4.2 Quantitative Results – Mission Performance Results

4.2.1 Visualization Time

The time soldiers took to learn the buildings with their visualization method was recorded. Soldiers were given a maximum time of 20 minutes for visualization. Soldiers in the No Aid condition did not perform the pre-mission visualization. The results are shown graphically for the Floor Plan and VE conditions, night and day in Figure 13 below. (Missing data includes 5 out of 72).



	Visualization Method		Significant Differences p<.05
	2. Floor Plan	3. VE	
Night	255 sec ± 303 sec	979 sec ± 341 sec	3>2
Day	195 sec ± 95 sec	878 sec ± 419 sec	3>2

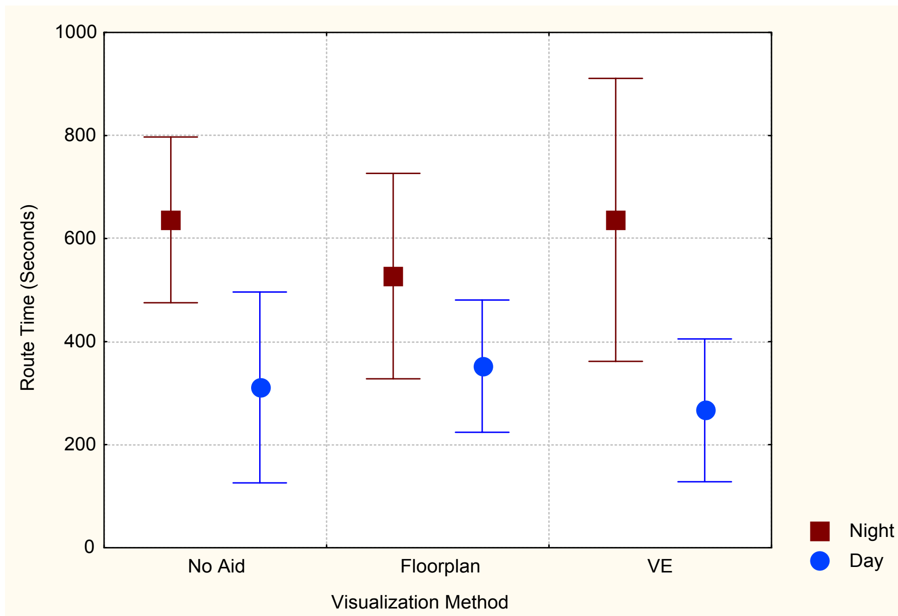
Figure 13: Visualization time by visualization method

For both night and day, the VE condition took significantly longer (3 to 4 times longer) than the Floor Plan condition.

The longer time required to use the VE was expected, since the VE contains much more information than the other two conditions. Also, simply getting through the entire VE using the controls took some time, especially if the soldiers were unfamiliar with the controls. The reduction of time in the day condition suggests growing familiarity with the VE controls.

4.2.2 Route Time

The mean time the soldiers took to complete their routes was analyzed for each visualization method. The time elapsed during the measurement points was not included in the calculation of route time. Figure 14 shows the route time results for night and day. (Missing data includes 2 out of 72).



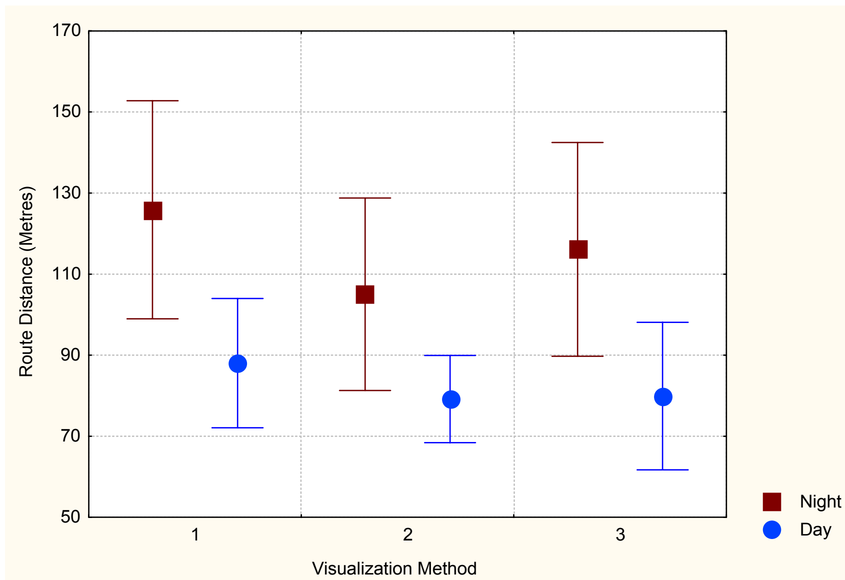
	Visualization Method			Significant Difference s p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	636.3 sec ± 160.9 sec	527.2 sec ± 199.5 sec	636.2 sec ± 160.9 sec	None
Day	311.0 sec ± 185.2 sec	352.3 sec ± 128.4 sec	266.6 sec ± 138.6 sec	None

Figure 14: Route times

There were no significant differences in route times for any of the conditions. This may be due to differences in the techniques or style used by the soldiers as opposed to the visualization method used. Although all soldiers were instructed to get to the objective as quickly and efficiently as possible, soldiers used many different styles as they navigated the building. Some tried to get directly to the objective, while some were more tactical in their approach (verifying all rooms were cleared along the route). Such variability may have masked any differences in route times.

4.2.3 Route Distances

The length of the route taken was compared for each visualization condition. The two routes in the experiment were of equal length and the means were calculated by condition. The route distance results are presented in Figure 15 below. (Missing data includes 5 out of 72).



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	125.9m ± 26.9m	105.0m ± 23.8m	116.1m ± 26.4m	1>2*
Day	88.0m ± 15.9m	79.2m ± 10.7m	79.9m ± 18.2m	None

* significant at $p < .10$

Figure 15: Route distances

Only one marginally significant ($p < 0.1$) difference was found in route distances. At night, soldiers who used the floor plan took a shorter route than those who received no aid.

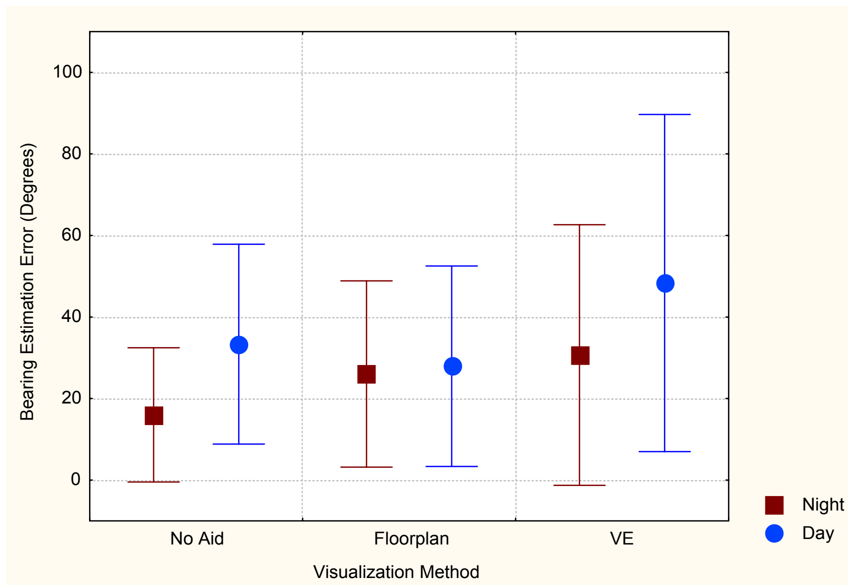
As with route time, the lack of differences and wide standard deviations in route distances may be attributed to the individual soldier's style as he navigated the building. The trend for distances shows the shortest route was taken when the soldier used the floor plan, and the longest with No Aid. Trends indicated that performance in all conditions improved from night to day. A large improvement was seen in the VE condition. This may indicate that experience with the VE is disproportionately beneficial, or that there are significant benefits when both the VE and the real environment are used for rehearsal.

4.2.4 Bearing Estimation Errors

During each run, soldiers were stopped at two separate measurement points and asked to estimate the bearing to the objective and the bearing to the start point. The average errors for these bearing estimations were analyzed for each visualization condition.

4.2.4.1 First Measurement Point to Start Point

The bearing estimation error results from the first measurement point to the start point are shown in Figure 16 below.



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	16.0° ± 16.5°	26.0° ± 22.8°	30.7° ± 32.0°	None
Day	33.3° ± 24.5°	27.9° ± 24.6°	48.3° ± 41.3°	None

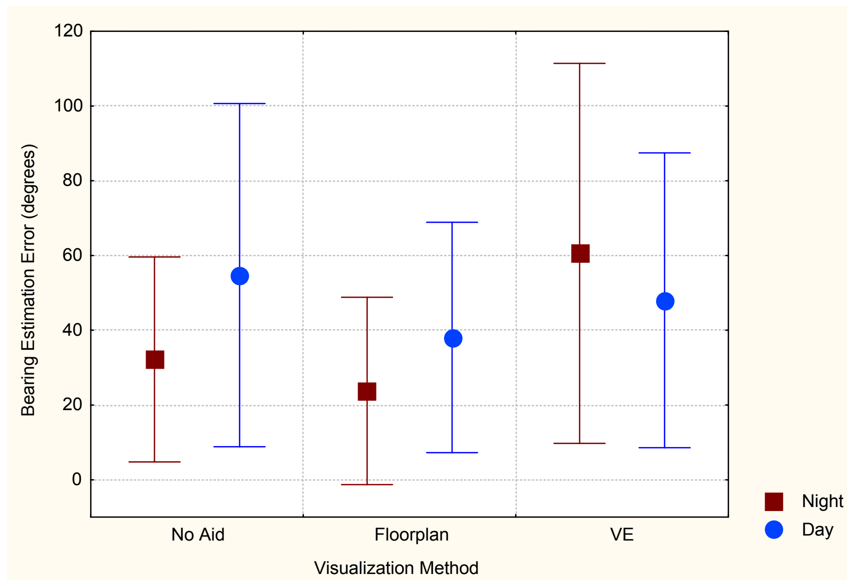
Figure 16: Bearing estimation error: first measurement point to start point

There were no significant differences between visualization groups in the bearing estimations from the first measurement point to the start point.

Because the soldiers had quite recently passed the start point when they reached the first measurement point, the performance on this task was affected by "real-world' experience in the buildings and not solely the visualization method used. This may explain why soldiers in the No Aid condition performed as well as those who received aids.

4.2.4.2 First Measurement Point to Objective

The bearing estimation error results from the first measurement point to the objective are shown in Figure 17 below.



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	32.2° ± 27.4°	23.8° ± 25.1°	60.6° ± 50.8°	2<3 1<3*
Day	54.8° ± 45.9°	38.1° ± 30.8°	48.0° ± 39.4°	None

*Significant at $p < .10$

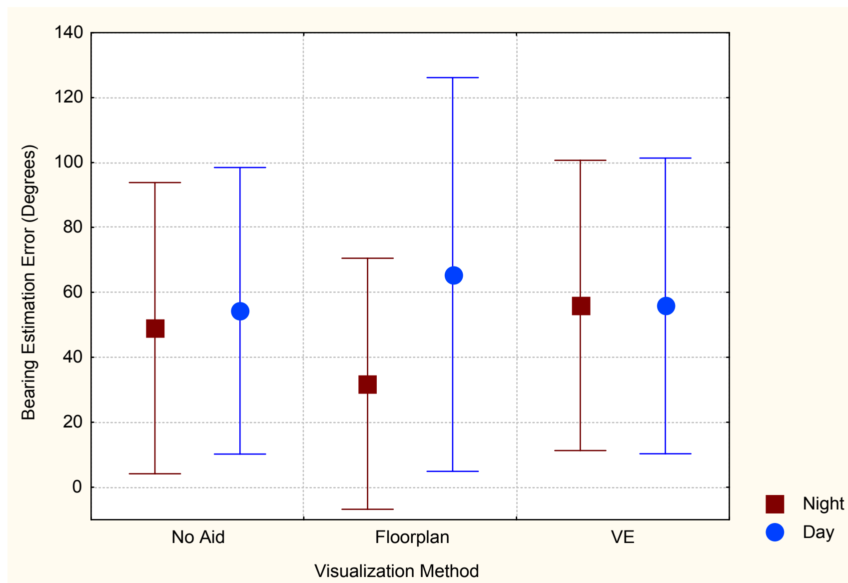
Figure 17: Bearing estimation error: first measurement point to objective

For bearing estimations from the first measurement point to the objective, significant differences appear only at night. Those who used the floor plan made smaller estimation errors than those who used the VE. At $p < .10$, those who received No Aid also made better estimations than those who used the VE. Trends show that while estimation error in this category decreased from night to day in the VE category, the mean error actually increased from night to day in the No Aid and Floor Plan condition. Although not statistically significant, estimations by those in the Floor Plan condition remained better than those who used the VE or No Aid In both nighttime and daytime conditions.

The poorer performance in the VE compared to other conditions could be attributed to an overwhelming amount of information in the VE, which may have detracted from in-situ learning. Similar to the results of Richardson et al. (1999) and Darken and Goergen (1999), soldiers in this experiment reported that the VE was disorienting and suggested the addition of a compass feature.

4.2.4.3 Second Measurement Point to Start Point

The bearing estimation error results from the second measurement point to the start point are shown in Figure 18 below.



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	49.0° ± 44.9°	31.8° ± 38.7°	56.0° ± 44.7°	None
Day	54.3° ± 44.1°	65.5° ± 60.6°	55.8° ± 45.5°	None

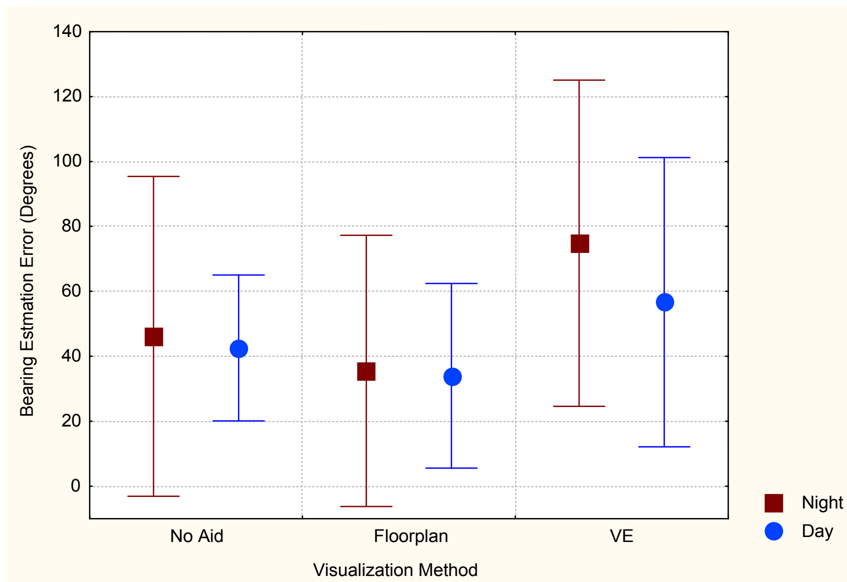
Figure 18: Bearing estimation error: second measurement point to start point

Consistent with results from the first measurement point, there were no significant differences between visualization groups for estimation errors from the second measurement point to the start point.

This suggests that real-world experience is a more influential factor in estimating bearing than the visualization method used.

4.2.4.4 Second Measurement Point to Objective

The bearing estimation error results from the second measurement point to the objective are shown in Figure 19 below.



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	46.2° ± 49.3°	35.5° ± 41.8°	74.8° ± 50.2°	2<3*
Day	42.6° ± 22.5°	34.0° ± 28.4°	56.7° ± 44.5°	None

*Significant at $p < .10$

Figure 19: Bearing estimation error: second measurement point to objective

There was only one significant difference at $p < .10$ in bearing estimation performance from the second measurement point to the objective. At night, soldiers in the VE condition made significantly worse estimates than those who used the floor plan. In the day, this difference was not significant.

Trends show improvement between night and day estimations. This may be attributable to more familiarity with the buildings, the ability to see more visual cues in the day as opposed to the night, and, for those in the VE condition, learning how to use the technology.

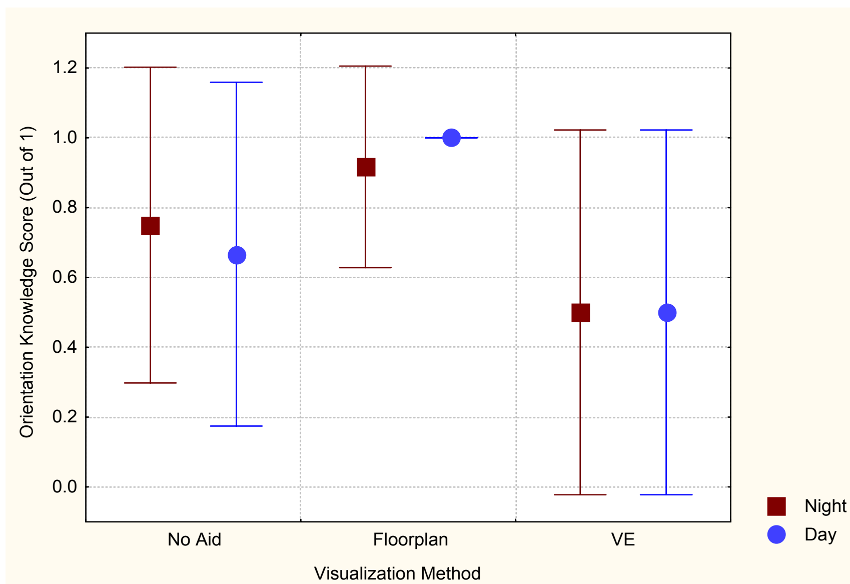
At both the first and second measurement point, soldiers (particularly in the VE condition) performed worse on estimations to the objective than on estimations to the start point. This is likely because the real start point had actually been visited when the bearing estimation had to be made, while the objective was still only mentally represented.

4.2.5 Terrain Reconstruction

Each soldier drew a 2D reconstruction of the buildings after his visualization session and before beginning his mission. The maps were marked for Orientation, Landmark Knowledge, Room Knowledge (Survey Knowledge), Room Knowledge (Route Knowledge), Mission Knowledge, and Reconstruction Quality. An ANOVA was performed between visualization conditions for all items.

4.2.5.1 Orientation

The Orientation results are shown graphically in Figure 20 below. Each map reconstruction was given a mark of 1 if North was indicated correctly, or 0 if North was indicated incorrectly or not indicated.



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	0.8 ± 0.4	0.9 ± 0.3	0.5 ± 0.5	2>3
Day	0.7 ± 0.5	1.0 ± 0.0	0.5 ± 0.5	2>1* 2>3

*Significant at $p < .10$

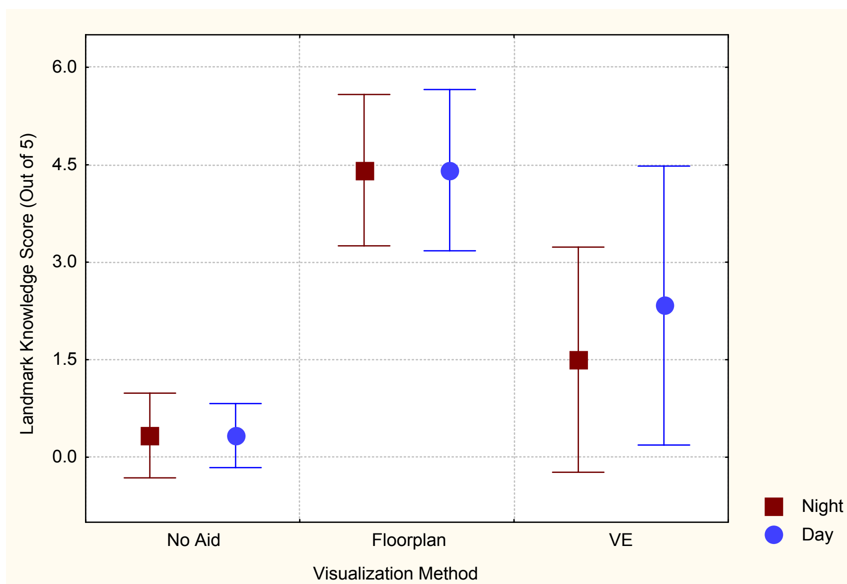
Figure 20: Orientation Scores

For both night and day, soldiers in the Floor Plan condition performed significantly better in the Orientation category than soldiers in the VE condition. During the day, the Floor Plan soldiers also performed marginally better ($p < 0.10$) than those who received No Aid. There were no other significant differences.

The walkthrough interface of the VE may have been disorienting, accounting for the difference between the VE and the Floor Plan. The performance with No Aid was not significantly different than the VE performance. Because the No Aid soldiers had little else to remember, they may have done better on the orientation task. Comments indicated that orientation with the floor plan was easier because the method clearly references North in relation to the 2D plan, whereas the 3D VE only stated the North heading upon entry into the VE. Some focus group comments indicated that orientation in the VE was easier if the soldier used the staircases as "waypoints" in his mental model of the building.

4.2.5.2 Landmark Knowledge

The Landmark Knowledge category tested awareness and positioning of landmarks (eg. stairs). Scores are presented in Figure 21 below. Points were earned in this category for correctly indicating the type and location of staircases and the building crossover point. Higher scores indicate more landmark knowledge. A maximum score of 5 points was possible in this category.



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	0.3 ± 0.7	4.4 ± 1.2	1.5 ± 1.7	2>3>1
Day	0.3 ± 0.5	4.4 ± 1.2	2.3 ± 2.1	2>3>1

Figure 21: Landmark knowledge scores

For both day and night, those that used the floor plan showed significantly more landmark knowledge than both other categories. Furthermore, those who used the VE performed significantly better than those with No Aid.

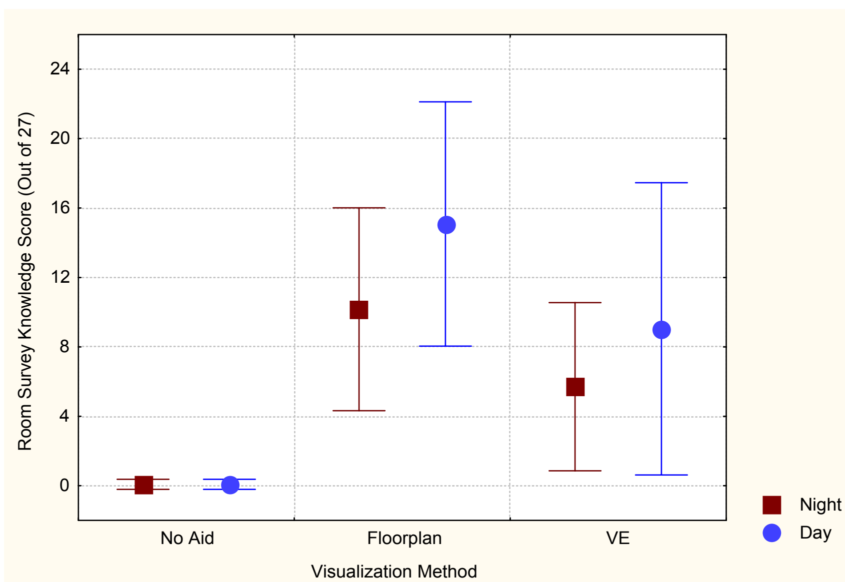
It is understandable that those in the No Aid category performed worse than the other conditions for landmark knowledge, because they received no information on location of landmarks, and only a verbal description of the entry, building crossover point and objective.

Because the Floor Plan had less total information than the VE, landmarks may have been easier to pick out and locate on a map reconstruction. Differences may also reflect the type of mental model development suggested by the visualization tool. The plan view perspective of the Floor Plan is well suited to building survey knowledge while the VE tool requires the user to construct a survey model through room exploration and route discovery. Development of survey knowledge may also be difficult in the absence of whole-body, kinesthetic movement cues, as suggested by Grant and Magee (1998).

Comments indicated that structural landmarks (e.g. stairs, room corners, windows, etc.) are often more reliable reference points for visualization and are less likely to change prior to a mission than equipment or furnishings. Focus groups comments emphasized the need to keep landmarks simple, such as prominent immovable landmarks like a staircase. In addition, participants commented that the ability to look out the window for exterior landmarks in a VE would be beneficial.

4.2.5.3 Survey Knowledge

The survey knowledge category tested knowledge of the number and placement of all rooms in the buildings. One point was awarded for each correctly identified room. A total of 27 points were possible for correctly identifying all the rooms in both buildings. Results are shown below in Figure 22.



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	0.1 ± 0.3	10.2 ± 5.8	5.7 ± 4.8	2>3>1
Day	0.1 ± 0.3	15.1 ± 7.0	9.0 ± 8.4	2>3>1

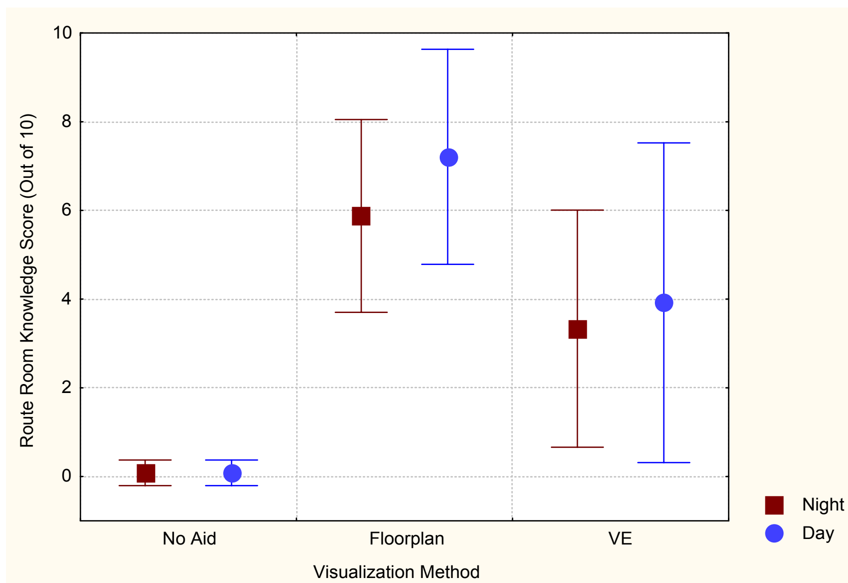
Figure 22: Room survey knowledge

In this category, for both day and night, soldiers in the Floor Plan condition performed better than soldiers in both the VE and No Aid conditions. Soldiers in the VE condition also performed better than soldiers in the No Aid condition.

Comments echoed the results in this category. Soldiers indicated that the floor plan layout was easier to memorize than the VE.

4.2.5.4 Route Knowledge

Route Knowledge tested knowledge of the placement and number of rooms on the primary mission route only. One point was awarded for each correctly indicated room on the mission route. A total of 10 points was possible for correctly indicating all the rooms on the mission route. Results are shown below in Figure 23.



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	0.1 ± 0.3	5.9 ± 2.2	3.3 ± 2.7	2>3>1
Day	0.1 ± 0.3	7.2 ± 2.4	3.9 ± 3.6	2>3>1

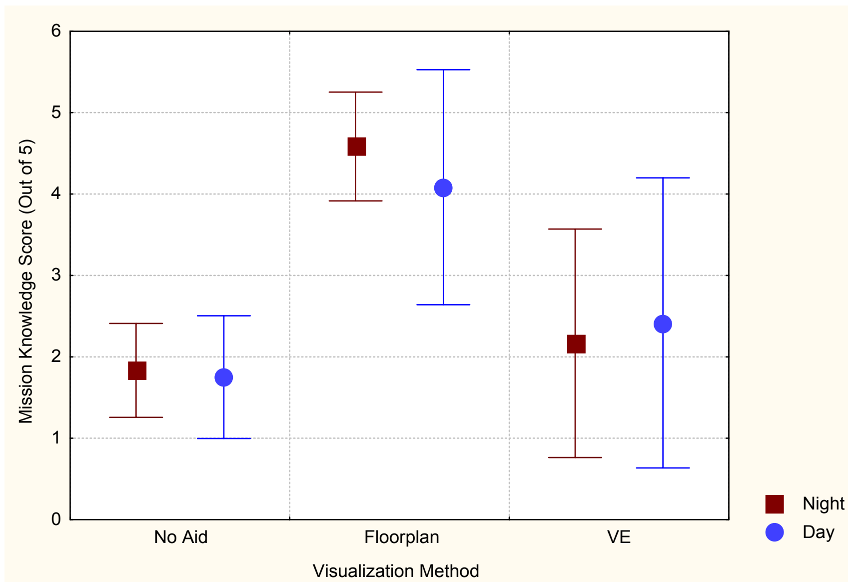
Figure 23: Route room knowledge

In this category, day and night, Floor Plan soldiers performed better than both VE and No Aid soldiers. VE soldiers also performed better than the No Aid soldiers.

These results indicate that the floor plan was the easiest method to use for memorizing the placement and number of rooms along the primary mission route.

4.2.5.5 Mission Knowledge

The Mission Knowledge category tested awareness of mission features including the number of doors passed through on the mission, the objective location and the start point location. Five points were possible. Higher scores indicate more mission knowledge. Results in this category are detailed below in Figure 24.



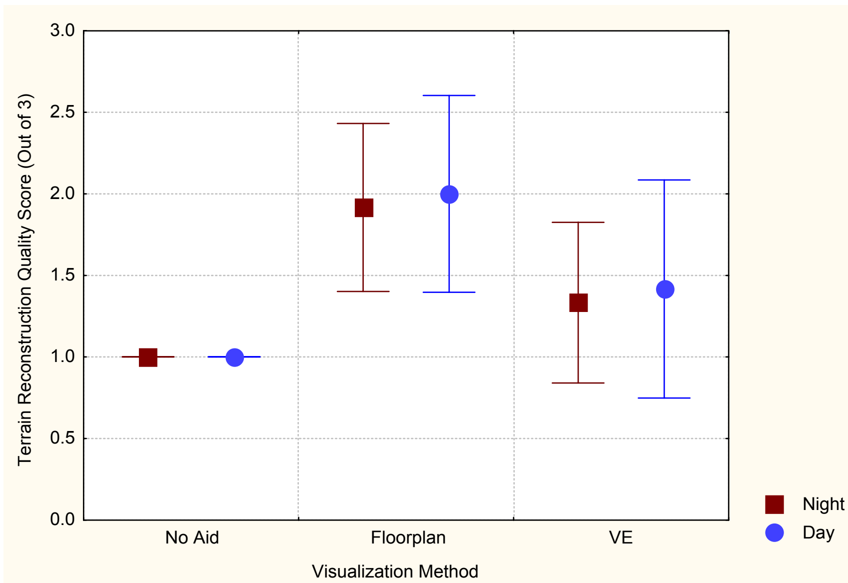
	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	1.8 ± 0.6	4.6 ± 0.7	2.2 ± 1.4	2>1,3
Day	1.8 ± 0.8	4.1 ± 1.4	2.4 ± 1.8	2>1,3

Figure 24: Mission knowledge scores

For both day and night, soldiers in the Floor Plan condition performed significantly better than those in the VE condition and No Aid condition in identifying the mission elements. These results may indicate that the mission elements were easier to translate onto a 2D terrain reconstruction when they were learned in a 2D manner (i.e. the floor plan) than when they were learned in the 3D VE.

4.2.5.6 Reconstruction Quality

The overall quality of the terrain reconstruction was judged subjectively by the marker on a scale of 1 to 3. One point was given if the drawing was not at all similar to the buildings. Two points were given if the drawing was somewhat similar to buildings. Three points were given if the drawing was extremely similar to the buildings. The Reconstruction Quality scores are shown below in Figure 25.



	Visualization Method			Significant Differences p<.05
	1. No Aids	2. Floor Plan	3. VE	
Night	1.0 ± 0.0	1.9 ± 0.5	1.3 ± 0.5	2>3,1
Day	1.0 ± 0.0	2.0 ± 0.6	1.4 ± 0.7	2>3,1 3>1*

*Significant at $p < .10$

Figure 25: Reconstruction quality scores

For both night and day, the reconstruction of the actual buildings was better for the Floor Plan condition than the other two conditions. Furthermore, the VE soldiers performed only marginally ($p < 0.10$) better than the No Aid soldiers in the day condition. The improvement from night to day of the VE soldiers may indicate that the VE combined with experience in the real environment is an effective way to learn an environment.

The nature of the reconstruction task may have favoured the Floor Plan condition, because the task involved a memorization and reproduction task, while those in the VE condition had to memorize the layout and then transform what they had learned into a Floor Plan format and those in the No Aid condition had to construct the design from their own imagination. Individual drawing abilities may have had an effect as well. It may be that a soldier had a good representation in his head, but had difficulty transferring that representation to paper.

4.3 Comments and Focus Group Discussions

Comments from the pre-mission and post-mission questionnaires focused on soldiers' likes, dislikes and possible improvements for each visualization method.

No Aid: The soldiers that received no aid indicated that the approach was "quick" and "simple". Some participants expressed that little or no visualization aid may be beneficial because it required less information to process, did not create expectations for items that might be modified, and forced the soldier to clear each room, a standard operating procedure. However, the No Aid condition lacked sufficient amounts of critical information that would be necessary to actually carry out such a mission confidently and with a detailed plan. To improve the approach, soldiers indicated that they would require additional information including a floor plan, interior layout, the type of building (e.g. residential or commercial), construction of walls, scale and distances, headings (e.g. north relative to the building), number of rooms, location and configuration of stairs, and information on the enemy (suspected locations, strength, size, morale, and activity).

2D Floor Plan: Soldiers who used the 2D floor plans liked the overhead view because it was "easy to visualize and memorize" and it allowed them to form plans and adjust to unexpected barriers. In addition, the methodology was thought to be more feasible than a VE because the format was believed to be more readily available and up-to-date than a computer generated virtual environment. Dislikes included the lack of information regarding the function of each room (e.g. living room, kitchen, etc.), what was in each room (e.g. furnishings and possible obstacles), types of wall construction, direction of door openings, size of rooms, and the top/bottom of the stairs. The floor plan also required a scale, as actual distances were shorter than expected. The floor plans could be improved by adding the information described above. As well, the floor plans could indicate ledges and holes in walls. Some participants placed less emphasis on the requirement for furniture location, as "you really don't care about furniture and placement of it because it is almost impossible to predict anyway". One soldier indicated that colour overlays could be included with the floor plan to provide the different types of information.

VE Tool: The VE visualization method was liked because it provided a large amount of detail on the layout and interior and had the capability to view a representation of the planned route. This helped to highlight items not well marked on 2D plans, such as closet and room configurations, lighting effects from windows, and line of sight from various locations. However, soldiers found the VE time consuming and difficult to use when judging distances. Distances estimations with the VE seemed larger or longer than reality. Some disliked the quality of the image, stating that "the image needs to be clearer, texture more lifelike", and "walls and corners tend to blend together making it difficult to see a corner". Almost all soldiers believed that the VE method might provide too much information if the scenario involved more buildings, or was more complex. As well, soldiers expressed some concern regarding its practicality. Soldiers questioned the ability of a VE environment to be kept "up-to-date" to reflect possible enemy locations, mine locations, etc. Soldiers mentioned the investment required to maintain the method is better suited for other operations, such as SWAT team tactics. To improve the VE method, soldiers expressed the desire for a scale, digital compass to indicate heading and the addition of a 2D floor plan view. The soldiers thought that the floor plan was good for overhead view, while the VE was useful for getting a better "feel" and awareness for what the room looks like. To help improve orientation within the building, soldiers also suggested the use of a "rolling compass" to constantly indicate their direction in relation to North, and possibly relative to the objective.

The section commander indicated that the tool would be beneficial for briefings, if marks could be added at various locations to help emphasize waypoints. Some soldiers had difficulty using the mouse input device, and recommended the use of a joystick for improved ease of use.

Comments in the focus group indicated that both the Floor Plan and VE tool visualization aids provided acceptable levels of awareness, allowing soldiers to adjust enroute to unexpected conditions. However, participants did suggest areas for improvement. Some soldiers commented that they would want more information from both the floor plan and the VE before entering a building, including the structural integrity of the building, total number of rooms and total number of doors. Comments indicated that the floor plan in particular needed more detail, such as the number and direction of doors, mouse hole / alcove possibilities and scale information, especially of the hallways. In planning, soldiers indicated the need for information that would allow them to identify possible points of ambush, barricades and booby-traps. A hybrid visualization tool, which combines the 2D floor plan perspective with the richer spatial insights from the VE tool, may well be the preferred solution.

Participants also cited many reasons why they demonstrated improved performance in the daylight conditions in comparison to the night conditions. Comments about the night portion of the experiment indicated the soldiers might have had some difficulty with the Night Vision Goggles. Visibility with the NVG's was confounded by fogging, instability, poor depth perception, and distraction created by the "strobe" effect of the in-building instrumentation. Having already conducted a session, participants were familiar with the procedures and the possible target locations, pass-through location, prominent landmark locations, furniture layout, and likely door directions.

The following information requirements were considered vital to the development of a mental model, regardless of the visualization method.

- Staircase locations (i.e. top and bottom)
- Room information (i.e. function, contents, mouse holes, windows)
- Door information (i.e. number, swing)
- Interior room layouts (size and number)
- Scale and distances
- Directional information (i.e. North)
- Overhead view of floor plan

Additional information that was desirable included:

- Type of building (i.e. residential or commercial)
- Construction of walls and structural integrity (i.e. brick or drywall)
- Enemy information (i.e. location, strength, size, morale and activity)

4.4. Results Summary

The major results of this experiment are presented below in Table 8.

	Measure	Significant Differences (p<.05) Night	Significant Differences (p<.05) Day
Qualitative (higher scores indicate increased acceptability)	Overall Acceptability (Pre-mission)	2,3>1	2,3>1
	Overall Acceptability (Post Mission)	2,3>1	2,3>1
Quantitative (higher scores indicate decreased performance)	Visualization Time (Floor Plan (2) and VE (3) only)	3>2	3>2
	Route Time	None	None
	Route Distance	1>2*	None
	Bearing Estimation Error (1st Measurement Point to Start Point)	None	None
	Bearing Estimation Error (1st Measurement Point to Objective)	3>2 3>1*	None
	Bearing Estimation Error (2nd Measurement Point to Start Point)	None	None
	Bearing Estimation Error (2nd Measurement Point to Objective)	3>2*	None
Quantitative (higher scores indicate increased performance)	Terrain Reconstruction—Orientation	2>3	2>1* 2>3
	Terrain Reconstruction—Landmark Knowledge	2>3>1	2>3>1
	Terrain Reconstruction—Survey Knowledge	2>3>1	2>3>1
	Terrain Reconstruction—Route Knowledge	2>3>1	2>3>1
	Terrain Reconstruction—Mission Knowledge	2>1,3	2>1,3
	Terrain Reconstruction—Reconstruction Quality	2>1,3	2>1,3 3>1*

1=No Aid, 2= Floor Plan, 3=VE * p<.10

Table 8: Summary of results

Overall qualitative questionnaire and comment data indicate that the floor plan or VE aids are better than No Aid. The No Aid condition was often rated unacceptable. There were few differences between the VE and the Floor Plan in the qualitative ratings. The VE was rated as unacceptable for the amount of time it required to use, but this rating improved with familiarity. Trends suggest that the Floor Plan is better for route planning and navigation and the VE is better for visualization and developing awareness of features (e.g. furnishings, view) at any location, which are reflected in the quantitative performance scores.

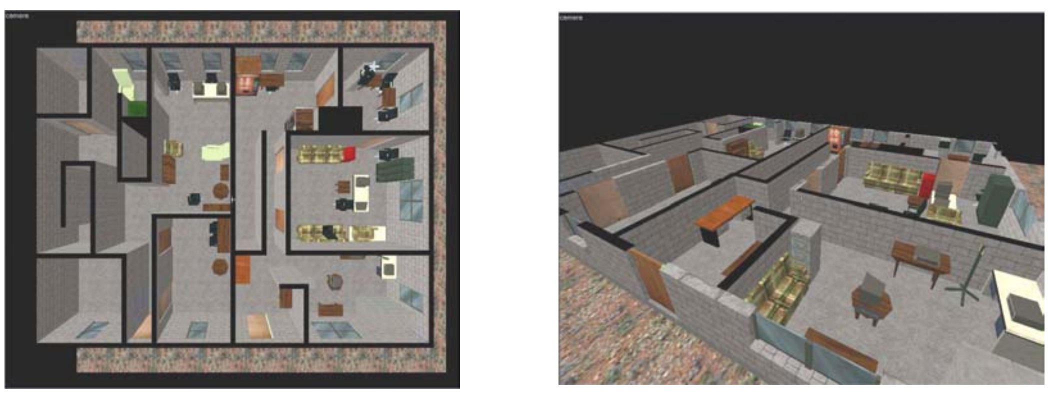
Quantitative results show that performance for the 2D Floor Plan group was significantly better than the VE group for time required for pre-mission visualization, bearing estimations to the mission objective at night and all aspects relating to terrain reconstruction. Terrain reconstruction was better for the VE group than the No Aid group for landmark knowledge, route knowledge, survey knowledge and reconstruction quality during the day. However the VE group did not perform better than the No Aid group with respect to mission knowledge, orientation and nighttime reconstruction quality.

In several measures, performance improved from night to day, particularly with the VE. Comments suggest this was a function of familiarization with the VE tool and the operational tasks. There were no measures, qualitative or quantitative, where performance using the VE was significantly better than performance with the Floor Plan. Clearly, this reflects the disorientation effects of a solely immersive VE tool. Such disorientation must be overcome before an immersive VE tool can be truly effective for in-building visualization.

5. Future Work

While the results of this experiment favour the use of a floor plan for in-building, pre-mission visualization, they also indicate that a VE could be a valuable mission rehearsal tool. Several areas for improvement in the VE that merit further research are suggested by the results.

Hybrid 2D/3D VE Tool: Many of the soldiers who participated in this research commented that while both the 2D floor plan and the 3D VE had benefits, a combination of the two would be most useful. A virtual walkthrough environment that also included the ability to view an overhead "floor plan" was suggested (see Figure 26 below). The benefits of such a system, compared to the basic "separate" systems should be investigated. This system could also incorporate other information that soldiers viewed as critical, such as scale information and a compass feature to help with orientation. Construct validity may be improved for the VE by introducing pace/walking sounds and movements to mimic pace counts. In addition, soldiers stated that the VE should not simply traverse over obstacles, but should actually act as barrier to the user to enforce the need to pause and consider the issues associated with various traversing strategies.



Plan view | **Isometric view**

Figure 26: VE tool with plan view capabilities

Additional information cues could also be added to the virtual space to highlight mission features, danger areas, extraction points, possible enemy locations, etc. A VE with the option to see through walls (as investigated by Sebrechts at al. 2000) could also be considered for enhancing spatial awareness and reinforcing the user's survey knowledge of the building.

Model Fidelity: Another area of interest is varying the fidelity of the terrain and features in the VE. The VE used in this experiment was quite detailed, showing all furniture, doors and windows. However, results from this experiment suggest that more detail may be beneficial in some instances. For example, detail on building materials for walls and floors, views out of windows and varying light levels. Since some soldiers found the amount of information overwhelming, confusing or unnecessary, lower fidelities should also be investigated. For example, less furniture could be included. Ideally, any future tool would have the capability to be scaled by the user to match their need for levels of detail. Further research is recommended to determine the optimum level of information preferred for different types or stages of a mission for a VE.

Control Interface: Different controls for the VE could also be tested. Some participants were not familiar with computer game packages, especially using a mouse as the input device. Those participants that had difficulty suggested the use of a joystick rather than a mouse to ease their movement through the VE.

Measures: Different measures of performance could be used to determine the effectiveness of different visualization methods. For example, in this experiment, shortest route distance and route time were used as indicators of mission success. However, these measures may run contrary to soldier priorities in actual urban operations. A different measure could involve instructing the soldiers to clear every room while they carry out their mission. The number of rooms properly cleared could then be analyzed. Another indirect measure of their understanding of the building layout may include the number of misdirections taken while enroute.

To ensure that all measurements were taken at exactly the same level of spatial difficulty, bearing estimations could all be taken at a single measurement point (vs. numerous) during the experiment.

Statistical Power: Statistical power in this experiment suffered from the high variability among soldiers for individual skills and preferred tactical styles. Pre-mission steps could be taken to ensure a more even balance between conditions. Groups should be balanced by skill prior to testing. This will ensure equivalent ability on visualization tasks such as map memory and building memory. Ideally, such an experiment could be carried out in a sufficient number of building locations to enable a repeated measures design so that some of this individual variability could be controlled as a within-subject effect.

Furthermore, because there was a range of computer experience within the VE group, some soldiers found the system easy to use, while others had difficulty navigating. A thorough training session should be conducted to teach the soldiers how to use the virtual environment and enable them to develop individual strategies. Soldiers should be required to demonstrate a high level of competency with the system before participating in the experiment to rule out computing skills as a factor.

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ANNEX A: Personal Information

PERSONAL INFORMATION

Identification Number	MOC
☐☐☐☐	☐☐☐☐

Skills

Please rate your planning skills:

○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent

Please rate your rehearsal skills:

○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent

Please rate your map reading skills:

○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent

Please rate your sense of direction:

○ Terrible ○ Poor ○ Fair ○ Good ○ Excellent

Please rate your ability to use night vision goggles:

○ Never Used One ○ Poor ○ Fair ○ Good ○ Excellent

Experience

Please rate your training and/or operational experience planning missions:

○ None ○ Some ○ Moderate ○ Extensive

Please rate your training and/or operational experience conducting task rehearsals:

○ None ○ Some ○ Moderate ○ Extensive

Please rate your training and/or operational experience using maps:

○ None ○ Some ○ Moderate ○ Extensive

Please rate your training and/or operational experience in urban operations:

○ None ○ Some ○ Moderate ○ Extensive

Please rate your training and/or operational experience using 1st Person computer games:

○ None ○ Some ○ Moderate ○ Extensive

ANNEX B:
Pre-Mission Questionnaire

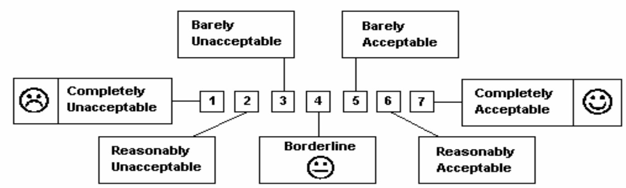
IN-BUILDING

Participant ID# : ________________ **Day** ○ **Night** ○

Visualization Method:	None	2D Floor Plan	3D Plan
	○	○	○

Entrance:

C4A	C4B
○	○



	Acceptability ☹ 1	2	3	☺ 4	5	6	☺ 7
Effectiveness of Method for:							
Route Planning	○	○	○	○	○	○	○
Awareness of Building Layout	○	○	○	○	○	○	○
Accuracy of Building Knowledge	○	○	○	○	○	○	○
Completeness of Building Knowledge	○	○	○	○	○	○	○
Awareness of Mission Features	○	○	○	○	○	○	○
Confidence in Method for:							
Planning Route	○	○	○	○	○	○	○
Navigating Building	○	○	○	○	○	○	○
Mental Workload of Method:							
Time Pressure during Visualization	○	○	○	○	○	○	○
Complexity of Information	○	○	○	○	○	○	○
Ease of Interpreting Information	○	○	○	○	○	○	○
Ease of Creating Mental Image of Building	○	○	○	○	○	○	○
Ease of Estimating Distances	○	○	○	○	○	○	○

	Acceptability ☹ 1	2	3	😐 4	5	6	☺ 7
Generally:							
Contribution to In-building Awareness	○	○	○	○	○	○	○
Ease of Acquiring Visualization Knowledge	○	○	○	○	○	○	○
Mental Workload to Use Knowledge	○	○	○	○	○	○	○
Time Required to Use Method	○	○	○	○	○	○	○
Ease of Using Method	○	○	○	○	○	○	○
Confidence in Visualization Knowledge	○	○	○	○	○	○	○
OVERALL ACCEPTABILITY OF METHOD	○	○	○	○	○	○	○

Likes Dislikes

Indicate the features/information you liked the most.	Indicate the features/information you liked the least.

Improvements

How would you improve this visualization method?

Additional Comments

ANNEX C:
Post-Mission Questionnaire

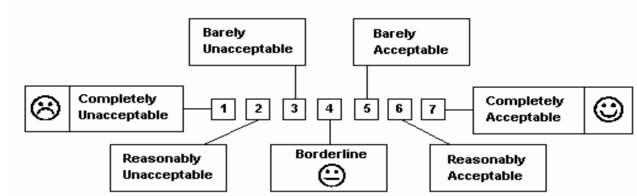
IN-BUILDING

Participant ID# : ________________ **Day** ○ **Night** ○

Visualization Method: None ○ 2D Floor Plan ○ 3D Plan ○

Entrance:

C4A ○ **C4B** ○



	☹ 1	2	3	☺ 4	5	6	☺ 7
Effectiveness of Method for:							
Route Planning	○	○	○	○	○	○	○
Changing a Mission Route on the fly	○	○	○	○	○	○	○
Awareness of Buildings	○	○	○	○	○	○	○
Awareness of Own location	○	○	○	○	○	○	○
Awareness of Objective location	○	○	○	○	○	○	○
Mental Workload of Method:							
Ease of Planning Route	○	○	○	○	○	○	○
Ease of Navigating In-building	○	○	○	○	○	○	○
Ease of Detecting Targets	○	○	○	○	○	○	○
Ease of Relating Real Building to Visualization Method	○	○	○	○	○	○	○
Ease of Estimating Distance	○	○	○	○	○	○	○
Time Pressure during Navigation	○	○	○	○	○	○	○
Ease of Estimating Locations	○	○	○	○	○	○	○

	Acceptability ☹ 1	2	3	😐 4	5	6	☺ 7
Generally:							
Contribution to In-building Awareness	○	○	○	○	○	○	○
Ease of Acquiring Visualization Knowledge	○	○	○	○	○	○	○
Mental Workload to Use Knowledge	○	○	○	○	○	○	○
Confidence in Visualization Knowledge	○	○	○	○	○	○	○
OVERALL ACCEPTABILITY OF METHOD	○	○	○	○	○	○	○

Likes Dislikes

Indicate the features/information you liked the most.	Indicate the features/information you liked the least.

Improvements

How would you improve this visualization method?

Additional Comments

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12QG01	W7711−017747/001/TOR
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