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The Effect of Physical Load and Environment on Soldier Performance

by Ellen C. Haas, Harrison Philip Crowell, and Kathy L. Kehring

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14. ABSTRACT

A study was conducted to characterize the interaction between physical load and environment on dismounted Soldier performance in navigation and auditory vigilance tasks. Three issues were explored: the effect of a 24-kg physical load on performance, the effect of real and virtual environments on performance, and the potential of radio check response time, duration, and accuracy as measures of cognitive performance. Handheld paper maps were used to navigate through four different environments: a warehouse site with no load carried, a warehouse site while wearing a 24-kg (53-lb) load, a virtual warehouse environment shown on a computer monitor, and a virtual warehouse environment shown on a CAVE display, all while listening and responding to radio checks. Results indicate that physical load and environment affect navigation and radio check task performance. Carrying a load increased navigation time but decreased radio check response time. Navigation times were longer in the virtual environments than in the Warehouse Without Load condition, and more navigation errors occurred in the virtual than in both real environments. Radio check response duration was longer in the CAVE than the other environments. The results also indicate that the radio check task can be a meaningful metric of cognitive performance.

15. SUBJECT TERMS

physical performance, cognitive performance, virtual environment, navigation, radio check, load carriage

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1. Introduction

U.S. Army dismounted Soldiers perform tasks that require physical and cognitive resources. For example, dismounted Soldiers often attend to information from radio networks and communicate with members of their squad (a task involving cognitive skills) while simultaneously using a map to navigate over unfamiliar terrain (a task involving cognitive and perceptual/motor skills). While performing these tasks, Soldiers must also be capable of moving their body mass plus an external load during high-speed, potentially prolonged tactical operations (Mahoney et al., 2007).

Technologies have been developed to assist the dismounted Soldier in performing his/her mission. Handheld communication and navigation devices have been developed to provide dismounted Soldiers with additional capabilities to enhance their knowledge of the battlefield. For example, the Rifleman Radio (AN/PRC-154) was designed to allow voice and data communication as well as tracking of individual Soldier GPS locations for navigation (Bertucca, 2012; DOD Programs, 2011; General Dynamics, 2013). However, when using these systems, the effect of physical load and the presence of other battlefield tasks (e.g., monitoring radio messages while navigating across the battlefield) will significantly affect how successful the Soldier is at detecting, processing, and responding to important battlefield information.

Technologies such as virtual environments have been developed to allow dismounted Soldiers to train while mitigating risk. One such immersive virtual reality system, the Dismounted Soldier Training System at Fort Bragg, NC (Bymer, 2012), was designed to provide dismounted Soldiers with training in several different battlefield conditions, while allowing the performance of navigation and radio communication tasks in real time. Although virtual simulations exist to train Soldiers for battlefield tasks, little research exists that compares Soldier performance in both real and virtual (simulated) battlefield tasks.

Few researchers have tested the effectiveness of Army-relevant auditory vigilance tasks such as radio check tasks as tools for measuring dismounted Soldier cognitive performance. Although Crowell et al., (in press) used a radio check task, this task was relatively undemanding as a cognitive stressor. During the Crowell et al. radio check task, the Soldier participants did not have any other cognitive tasks to attend to, and the only messages on the “radio network” were the radio check messages.

The current experiment investigated three issues: (1) the effect of different physical loads on Soldier performance of navigation and radio check tasks, (2) the effect of real and virtual environments on Soldier performance of the same tasks, and (3) a more demanding radio check task to determine whether radio check response time, duration, and accuracy had potential as measures of Soldier cognitive performance.

1.1 The Effect of Physical Load on Soldier Performance

There is little agreement regarding how physical load or physical exertion affects performance in navigation and radio check tasks. Some researchers found a beneficial relationship between load carriage and cognitive performance. Hogervorst et al. (1996) found improved performance on cognitive tasks after exercise on a cycle ergometer. Lybrand et al. (1954) assessed the effects of a 5-mile march with a 40-lb pack on the perceptual ability of college students, finding that scores on perceptual tasks were higher after mild physical activity than during periods of no exercise and sleep deprivation. Gliner et al. (1979) observed that aerobic energy produced in a marathon race facilitated the performance of adult men in a vigilance signal-detection task.

Some researchers found a detrimental relationship between load carriage and cognitive performance. Mahoney et al. (2007) found that walking affects concurrent cognitive performance in a secondary auditory vigilance task, and that there were fewer correct vigilance task responses when carrying a load or when walking over obstacles compared with standing still with and without a load. Knapik et al. (1990) found significant decrements in military performance after Soldiers had completed a 20-km road walk while carrying a total of 101 lb. This load not only made the road march extremely strenuous, but led to inhibited grenade throw performance and decreased marksmanship accuracy. In addition, after the road march, the Soldiers reported a significant decline in vigor and increase in fatigue. Drain et al. (2010) noted that prolonged load carriage may deplete or diminish cognitive performance, but that with high physical demands there were no changes in cognitive performance on a complex synthetic work task conducted after the completion of a road march task. Kobus et al. (2011) found that cognitive performance degraded with increasing load carried, physiological strain and cognitive performance were negatively correlated, and cognitive performance was positively correlated with perceived comfort and negatively correlated with perceived heaviness.

Some researchers found mixed results on the effects of load on cognitive ability. Knapik et al. (1997) found that strenuous load carriage (34–61 kg carried 20 km) led to decrements in subsequent physical performance but not in cognitive ability. Crowell et al. (1999) found that error rates in an auditory monitoring cognitive performance task were significantly lower for a light load (22.77 kg) than for a heavier load (36.94 kg). They also found that there were no significant differences in performance on arithmetic and memory tasks as a function of load. This may have been due to the structured presentation of the questions or because the physical exertion was not intense enough to affect task performance.

Mahoney et al. (2007) hypothesized that the lack of agreement between research results may be due to differences in the nature, duration, and intensity of the physical exertion of the experimental participants, the nature of the cognitive tasks used, and the fitness level of the participants. Other differences may have been due to some researchers obtaining data after rather than during exercise and load-bearing activities.

The load carriage aspect of the present study explored whether a relatively "light" load (24-kg fighting load in a rucksack) carried in a warehouse environment would have an effect on Soldier performance in a navigation task (requiring cognitive and perceptual/motor skills) and in an auditory radio check task (requiring cognitive skills). Performance on these two tasks while carrying the 24-kg load was compared with no load carried while navigating around the same warehouses, as well as in two virtual environments—virtual warehouses shown in a cave automatic virtual environment (CAVE) and virtual warehouses shown on a computer monitor. To decrease the problems noted by Mahoney et al. (2007), the fitness level of participants was similar; all participants were Soldiers, National Guard, or recent Army retirees, and all measures were taken during task activities. Based upon results of Kobus et al. (2011), it was hypothesized that performance in the navigation and the radio check tasks would be negatively correlated with load weight.

1.2 The Effect of Real and Virtual Conditions on Soldier Performance

Although virtual simulations exist to train Soldiers for battlefield tasks, little research has explored Soldier cognitive performance under comparable real and virtual environments. Witmer et al. (1996) found differences in the number of wrong turns, but not speed or route completion, when comparing participant performance while traveling a specific route within a real and a virtual building. These researchers found that participants trained in the virtual environment made more wrong turns than those trained in the real-world environment. In addition, Witmer and Kline (1998) found that tasks such as distance estimation are less accurate in a virtual environment than in the real world. Klein (1976) suggested that "moving per se does not always require attention; rather, it is the guidance of movement, in terms of direction and speed that requires attention." This would imply that guidance of movement in virtual worlds (e.g., with a joystick guiding direction and speed) demands more cognitive work than navigating a real-world environment.

In order to investigate Klein's (1976) suggestion that guidance of movement in virtual worlds demands more cognitive work than walking in a real world, this study partially replicated the methods used in Crowell et al. (in press). In the latter study, each participant performed a map navigation task in and around the U.S. Army Research Laboratory (ARL) warehouse complex without a physical load. In addition, Soldiers wearing no load used a joystick to navigate through a digital (virtual) representation of the ARL warehouse complex as experienced on a desktop computer and as experienced in the ARL CAVE environment. In their study, Crowell et al. had the Soldier walk on an Omni Directional Treadmill within the CAVE, but noise issues prevented complete analysis of the data from the radio task in that environment. Based on Klein (1976), it was hypothesized that navigation in virtual environments (following a course in CAVE and computer monitor environments) would require more attention (and thus more time) than navigation through real-world environments (following a course around the ARL warehouse with and without a 24-kg load).

1.3 The Potential of Radio Check Response Time, Duration, and Accuracy as Measures of Dismounted Soldier Cognitive Performance

To study the effects of Soldier cognitive performance, Crowell et al. (in press) used a radio check auditory vigilance task as a secondary task cognitive stressor, having Soldiers respond to targeted auditory radio check requests to engage Soldiers' spare mental capacity, while simultaneously performing a walking task on the ARL Ground Vehicle Experimentation Course at different set speeds. Pairing an auditory task with a simultaneous visual navigation task was thought to be advantageous; Wickens's (1984) multiple resource theory stated that different tasks can be processed in parallel if the tasks required different resource modalities. Scherer et al. (2002) suggested that auditory cognitive and attentional demands affect speech fluency and speech rate, and that measures used in the radio check task (response time, duration, and accuracy) are all measures of speech fluency and speech rate. Thus, by using the auditory modality for input and speech for output, it was thought that an auditory radio check vigilance task would not interfere with the navigation task's visual input and motor output.

In the present study, the radio check task was made more demanding than that used in Crowell et al. by inserting redesigned radio check messages within natural pauses in an otherwise continuous stream of simulated radio traffic. The radio traffic consisted of scripted messages spoken by actors posing as Soldiers performing an Army-relevant dismounted Soldier mission. In addition, a larger number of target and nontarget radio check messages were used, each of which required immediate Soldier response. It was thought that because the radio check task was embedded within almost constant radio traffic, Soldier attention would be engaged to a high degree, especially when used in tandem with the navigation task. It was hypothesized that Soldier response time and accuracy in the radio check task could provide an effective tool to measure dismounted Soldier cognitive performance. In the future, this redesigned radio check task could provide an effective tool to measure dismounted Soldier cognitive performance. Measures used in the radio check task (response time, duration, and accuracy) are all measures of speech fluency and speech rate (Scherer et al., 2002). Because of the relationship between cognitive performance and radio check task speech measures, it was hypothesized that radio check task response time, duration, and accuracy would have the potential for reflecting meaningful differences in Soldier performance.

2. Research Objective

The objective of this study was to develop a characterization of the interaction of physical load and environment on dismounted Soldier cognitive performance by exploring the effect of physical load on Soldier performance, the effect of real and virtual environments on Soldier performance, and the potential of radio check response time, duration, and accuracy as measures of dismounted Soldier cognitive performance. The resolution of these issues would allow researchers to choose the most appropriate and relevant environments and tasks for the study of physical and cognitive stressors on dismounted Soldiers. In addition, data from this study could be used to inform system design, mission load tradeoffs, and distribution of tasks, as well as provide input to modeling and simulation tools.

2.1 Hypotheses

2.1.1 The Effect of Physical Load on Soldier Performance

It was hypothesized that Soldier performance on the navigation and radio check tasks would be negatively correlated with load weight. It was also hypothesized that navigation and radio response performance time means for the 24-kg load environment would be significantly greater than the means for the no-load environments.

2.1.2 The Effect of Real and Virtual Environments on Soldier Performance

It was hypothesized that navigation in virtual environments (CAVE and computer monitor) would require more time and attention than navigation in real-world environments (Warehouse With Load and Warehouse Without Load). Thus, Soldier navigation and radio check mean performance for the virtual environments would be significantly greater than mean performance for the real-world environments

2.1.3 The Potential of Radio Check Response Time, Duration, and Accuracy as Measures of Dismounted Soldier Cognitive Performance

Radio check tasks employ cognitive processing. Because of the relationship between cognitive performance and speech measures used in the radio check task, it was hypothesized that radio check task response time, duration, and accuracy would reflect meaningful differences in Soldier cognitive performance in the different environments used in this study.

3. Method

3.1 Participants

There were 16 participants in this study, all of whom were active duty U.S. Soldiers, National Guard, or recent Army retirees. There were 15 males and 1 female between the ages of 22 and 40 (mean [M] = 28.54 years, standard deviation [SD] = 5.91). Fourteen participants (13 males and 1 female) were Soldiers from the 22d Chemical Battalion at Aberdeen Proving Ground (APG), Edgewood, MD. Two male participants (one an Army National Guard Explosive Ordnance Disposal Specialist and one a recent Army retiree currently working for the APG Special Weapons and Tactics Team) were recruited from a local temporary employment agency and were paid $30 per hour for their participation in this study. Of the 14 chemical battalion Soldiers from APG, two had the rank of private E-2, seven were specialists, one was a corporal, two were sergeants, one was a staff sergeant, and one was a sergeant first class.

All participants had an active driver's license and had self-reported good health and normal hearing and vision (including corrected vision). No participant had any illness or injury that would affect his/her ability to walk, see, or hear. The voluntary, fully informed consent of the persons who participated in this research was obtained by U.S. Army human use regulations (U.S. Department of Defense, 1999; U.S. Department of the Army, 1990).

3.2 Location

This study was conducted at two locations. All warehouse navigation tasks were conducted at the ARL Warehouse Site, Buildings 501–505, at APG. The Warehouse Site is approximately 5 acres in size, relatively flat, and has roadways paved with concrete, blacktop, or packed gravel. All virtual navigation tasks were performed at the ARL Tactical Environment Simulation Facility (TESF), Building 518, APG.

3.3 Apparatus

The experimental apparatus consisted of two simulation systems, a joystick, a U.S. Army rucksack, and hardware and software for the radio check task.

3.3.1 Simulation Systems

Two different TESF simulation systems were used to present the virtual warehouse environment to the participant. Each of the two systems showed the same software, which contained a digitized version of the ARL/APG Warehouse Site, Buildings 501–505, including all paths and roadways.

The first simulation system (a computer with a monitor) consisted of one Intel*-based Dell† computer with an Intel motherboard and a 256-MB video card that controlled the 24-in. flat panel computer monitor, which showed the virtual warehouse environment to the participant. The participant sat on a chair at a table with the monitor placed approximately 1.5 ft away from, and directly in front of, the participant (see figure 1).

Figure 1. Simulation system with computer monitor.

The second system was the CAVE, a projection-based immersive virtual reality system. The participant sat at a small table surrounded by four large display screens, each located 6.25 ft away from the participant (see figure 2). Each display screen measured 12.5- × 10-ft, and all were positioned at 90° to one another with the participant in the center. The screens provided the participant with a full 360° field of view of the terrain, providing the participant the experience of immersion in the virtual environment. The terrain images, generated by a cluster of four Intel-based Quantum 3-D, Inc., computers with 256-MB video cards, were rear-projected onto the CAVE screens by four projectors, each with a brightness rating of 6000 lm (Christie Digital Mirage 6000‡).

* Intel is a registered trademark of Intel Corporation, Santa Clara, CA.

† Dell is a registered trademark of Dell Incorporated, Round Rock, TX.

‡ Christie Digital Mirage 6000 is a registered trademark of Christie Digital, Cypress, CA.

Figure 2. Simulation system with CAVE display.

3.3.2 Joystick

A Cyborg 3D Rumble Force joystick (Saitek, Inc., San Diego, CA) was placed on the top of the table at which the participant sat and was used by the participant to control movement (direction and rate of travel) through each virtual warehouse environment. The maximum speed of travel through the virtual environment was limited to 4 mph (the average speed of travel through the real-world warehouse environment, as determined by Crowell et al. [in press]).

3.3.3 U.S. Army Rucksack

In environments in which participants carried a fighting load, each participant wore a U.S. Army rucksack on their back (see figure 3). A foam block with lead shot was placed inside the rucksack. The total weight of the rucksack with the foam block and lead shot was 24 kg (53 lb).

Figure 3. Rucksack carried for fighting load.

3.3.4 Hardware and Software for the Radio Check Task

All auditory stimuli (radio traffic and radio checks) were recorded and mixed using Sound Forge[*] version 4.5 software. One SanDisk Sansa Clip Zip MP3 Player[†] (1.0 × 1.0 in), connected to an Auvio[‡] miniature loudspeaker (1.0 × 1.5 × 0.35 in), was used to present all auditory stimuli to the participant. The auditory stimuli radio messages (Haas, 2012) were played at 68 dBA, as measured at the level of the participant's ear. A RipFlash Pro Digital Audio MP3 Player/ Recorder[§] (2.0 × 3.0 × 0.15 in) was used to record all participant responses, along with radio task stimuli. The audio hardware was attached to a metal audio apparatus fixture (2.0 × 4.0 in), which was attached to the front strap of the rucksack in the trials in which the rucksack was used. The fixture was attached to a lightweight harness worn by the participant for all conditions in which the rucksack was not worn (see figure 4). All audio equipment, including the fixture, weighed less than 32 oz. After the experiment, Sound Forge version 4.5 and Audacity version 1.3.12-beta audio software were used to analyze the radio check task audio data. Dragon Dictate[**] Speech Recognition software version 5.0 was then used to write the audio response time data into an Excel file, for import into SPSS software for the statistical analysis.

a **b**

Figure 4. Audio hardware attached to (a) rucksack and (b) harness.

3.3.5 Questionnaires

The four questionnaires used in this study consisted of: (1) the participant data form, a demographic questionnaire with additional questions including participant health status and previous computer experience; (2) the Santa Barbara Sense of Direction Scale (Hegarty et al.,

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[*] Sound Forge is a registered trademark of Sony Creative Software, Tokyo, Japan.

[†] SanDisk Sansa Clip Zip MP3 Player is a registered trademark of SanDisk Corporation, Milpitas, CA.

[‡] Auvio is a registered trademark of RadioShack Corporation, Fort Worth, TX.

[§] RipFlash Pro Digital Audio MP3 Player/ Recorder is a registered trademark of PoGo! Products, Inc., Brea, CA.

[**] Dragon Dictate is a registered trademark of Nuance Communications, Inc., Burlington, MA.

2002), to obtain information regarding participant self-reported spatial and navigational abilities; (3) the Perspective Taking/Spatial Orientation Test (Hegarty and Waller, 2004), to measure participant ability to imagine different perspectives or orientations in space; and (4) the final questionnaire, to measure the participant's level of comfort, physical effort, and ease of performance during both the audio and navigation tasks.

3.3.6 Other Apparatus

Reflective safety belts were worn by experimental participants and test administrators when they walked upon the streets and roadways of the ARL Warehouse Site.

3.4 Stimuli

3.4.1 Visual (Navigation Task) Stimuli

The participants used a map to navigate a specified route through the real and virtual ARL Warehouse Site environments. Four different maps were used in the study (one map for each of the four experimental trials), shown in figures 5–8. One additional map similar to those shown in figures 5–8 was used for training purposes. Each of the maps, which were hand drawn on two sides of 8.5- × 11-in white paper and laminated, had different routes through the ARL Warehouse Site. All map routes covered the same distance but on each map the direction of travel was different and each had a different starting point.

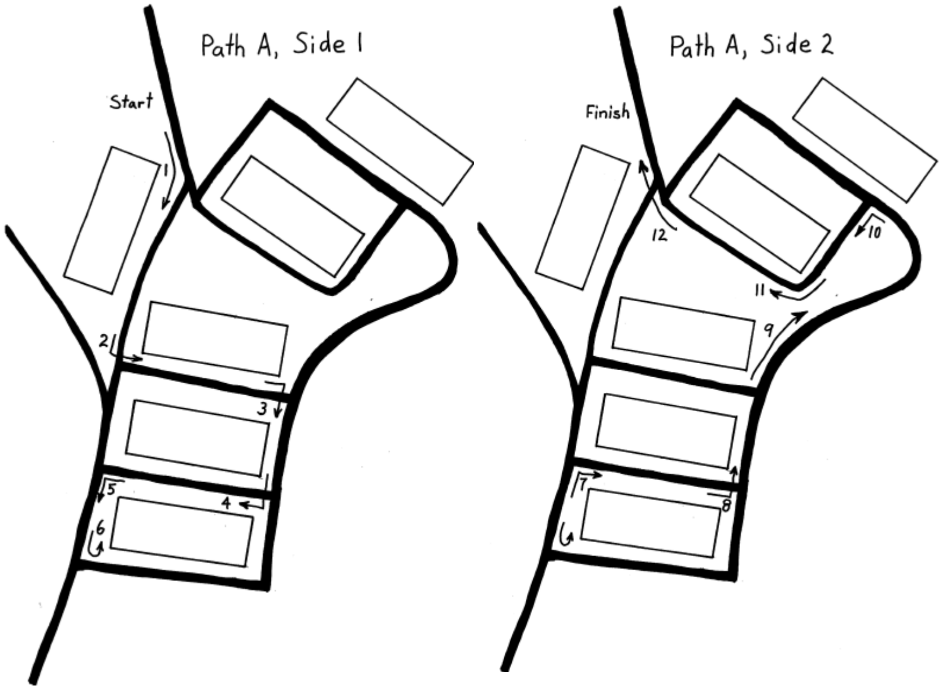

Figure 5. Map of path A around the warehouses.

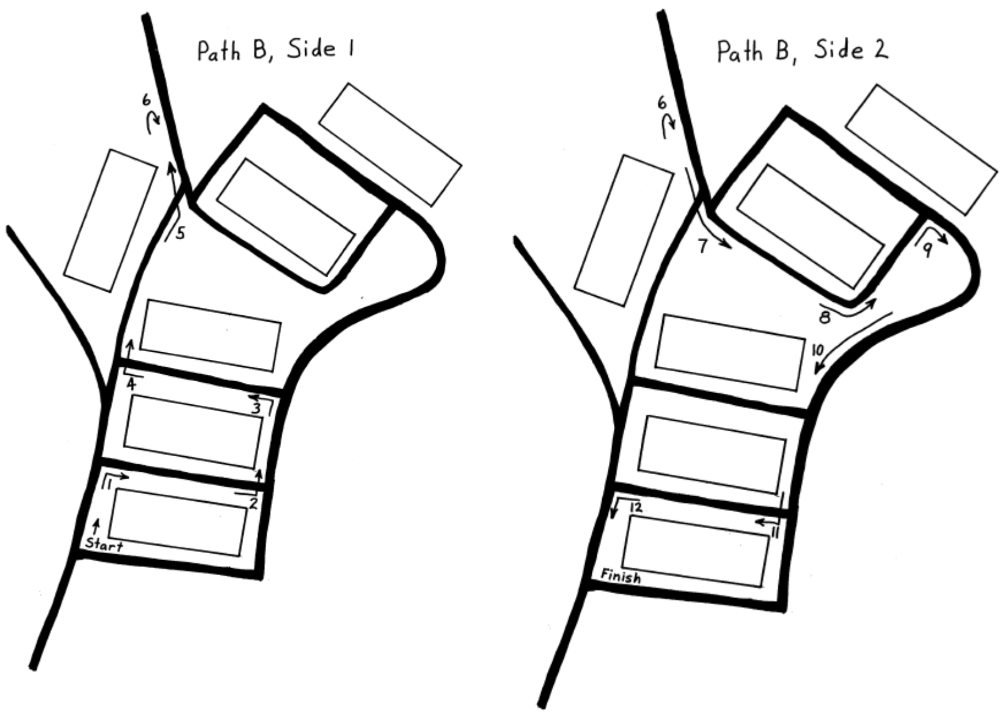

Figure 6. Map of path B around the warehouses.

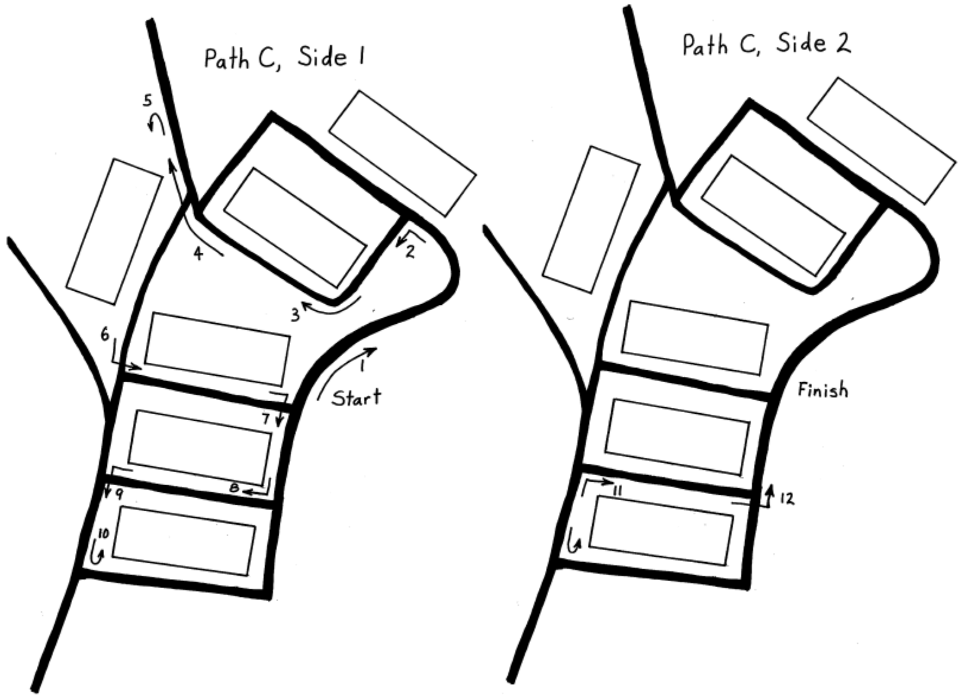

Figure 7. Map of path C around the warehouses.

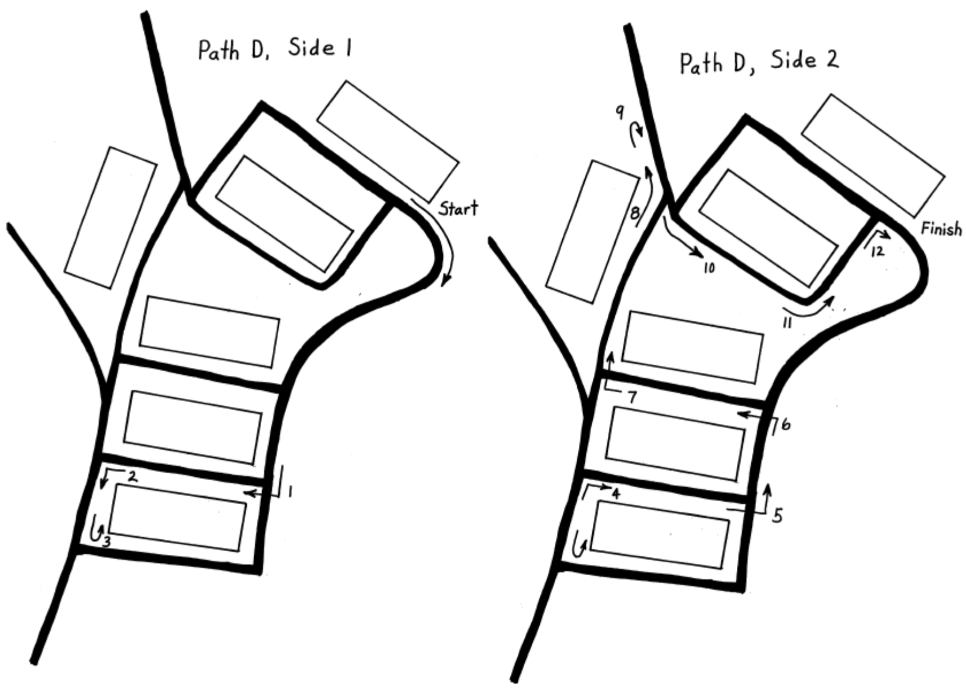

Figure 8. Map of path D around the warehouses.

3.4.2 Audio (Radio Check Task) Stimuli

An MP3 file of simulated U.S. Army radio traffic messages (Mermagen, 1992) was used to produce five different MP3 audio recordings (one for each of the four experimental trials and one for training) (Haas, 2012). The radio traffic recording included messages such as situation reports, line of advance messages, and instructions for squad members to move to other locations. For each of the five recordings, 30 different prerecorded target radio checks spoken by a male voice were presented in natural pauses in the radio traffic. Ten of the radio check messages were target radio checks in which the male voice spoke the call sign of the participant ("x-ray two-three"), identified himself, and requested a radio check ("x-ray two-three, this is golf five-six, radio check, over"). This message cued the participant to reply with a specific phrase ("golf five-six, this is x-ray two-three, roger, out"). The remaining 20 messages were nontarget radio checks in which the same male voice requested a radio check from five different call signs other than "x-ray two-three" (e.g., "alpha two-five, this is golf five-six, radio check, over"). Each of the five nontarget call signs was repeated four times on each MP3 file. The participant was told not to reply to messages not targeted to him/her. Fifteen seconds of radio silence followed each of the target and nontarget radio check messages, providing time for the participant to respond if they chose. All five MP3 files had a total duration of approximately 14 min. All 10 target and 20 nontarget radio check messages were played within the first 8 min of each 14-min audio recording to ensure that the participant was exposed to all radio checks before he/she finished the navigation task. The navigation task was designed to take approximately 11 min to perform (as per Crowell et al., in press).

3.5 Procedure

Only one person participated per day, and for each participant, all environments were presented on that day. The participant was asked if he/she had normal hearing with no ear-related problems or infections. If the participants reported ear infections or if they did not meet the vision criteria (reported normal 20:30 vision or better with or without corrective lenses), they were not allowed to participate in the study. Participants who met the criteria were asked to read and sign the informed consent form (appendix A) and assigned a number to identify their data.

Next, the participant provided demographic and medical status information on the participant data form (appendix B) and completed the Santa Barbara Sense of Direction Scale and Perspective Taking/Spatial Orientation Test (appendixes C and D).

In this study, Soldiers used handheld paper maps to navigate through four different environments while listening to an audio recording and responding, as directed by the experimenter, to target radio checks. First, the experimenter trained the participant to perform the radio check task. The participant was told that their call sign would be "x-ray two-three" for the duration of the experiment. The participant listened to an example target radio check message, was told the correct response to that message ("[call sign of caller], this is x-ray two-three, roger, out"), and repeated that response to the experimenter. The participant was told to respond only to radio check messages where the caller used the participant's call sign. The experimenter then presented examples of nontarget radio check messages (messages that did not use the participant's call sign) to the participant and told the participant not to respond to those messages. Next, the participant listened and responded to a 3-min sample of simulated radio traffic that contained five target and four nontarget radio checks. The participant was given feedback on the correctness of his or her responses by the experimenter. After the participant made five correct responses to five sequential target radio check messages, that part of the training was complete.

Next, the experimenter familiarized the participant with the warehouse site, driving the participant around the warehouse area while he/she used the training map to locate the warehouse buildings and roads used in the navigation task. The experimenter also described the navigation task to the participant. During the drive, the experimenter answered all participant questions. After all questions were answered, this phase of training was complete.

The participant was then readied for the first navigation trial in the first environment. He/she donned the harness or rucksack for that condition along with the fixture containing the MP3 recorder and player. The participant was then handed one of the four navigation task maps, taken to the starting position, and then performed an experimental trial by navigating the route shown on the map while simultaneously listening to the audio recording and responding to the target radio checks. After the participant finished the navigation task, he/she was given a 10-min break.

After the break, the next trial started. The participant was given a different navigation map for the next environment and he/she was taken to the starting point. The participant performed the navigation task for that environment and responded to the target radio check messages. This procedure was repeated for each of the four experimental environments.

The participant performed a total of four trials, one in each of the four environments, each with a short break afterward. After completing the navigation task in the fourth and last environment, the participant was brought to the TESF, where he/she completed the final questionnaire (appendix E), the experiment ended, and the participant was free to leave.

3.6 Experimental Design

For the navigation tasks, radio check tasks, and questionnaires, the treatment structure was a within-subjects factorial design with one independent variable (environment). The four different environments were (1) ARL Warehouse Site, while wearing no rucksack (Warehouse Without Load), (2) ARL Warehouse Site, while wearing a 24-kg (53-lb) fighting load (Warehouse With Load), (3) TESF, while experiencing the virtual warehouse environment shown on a computer monitor (computer monitor), and (4) TESF while experiencing the virtual warehouse environment in the CAVE.

Experimental environments were assigned to participants by means of a Williams latin square design (Williams, 1949) to ensure that each treatment was administered first, second, third, and last, and no treatment consistently preceded or followed another. Different Williams latin squares were also used to counterbalance the order of presentation of the four navigation maps and the four radio simulations.

3.6.1 Dependent Variables

The four dependent variables are as follows:

1. Navigation task data were collected at each environment. The data consisted of:
    a. Navigation accuracy (number of participant response errors): these data included (1) number of times the participant took a wrong turn, (2) number of times the participant asked navigation directions from the experimenter or a road guard, and (3) number of times the participant made a fatal navigation error (disabled the computer simulation).
    b. Navigation time: the time required by the participant to travel from the starting line to the finish line for each mapped navigation path.
2. Radio check data were collected in each environment. The data consisted of:
    a. Radio check accuracy (number of participant response errors): these data included (1) number of times the participant responded to an incorrect call sign, (2) number of times the participant failed to respond to a correct call sign, and (3) number of times the participant repeated or omitted words in his or her call sign response.
    b. Participant response time: for correct radio check responses, the time from the onset of the radio check request to the onset of the participant's response.
    c. Participant response duration: for correct radio check responses, the time from the onset of the participant response to the end of the offset of the final word of the participant response.
3. Final questionnaire data for each environment. The data consisted of:
    a. The rated level of comfort and physical effort for all environments, for both the radio check and navigation tasks.
    b. The ranked order of ease of performance for all environments, for both the radio check and navigation tasks.
4. Spatial ability data consisted of:
    a. Scores from the Perspective Taking/Spatial Orientation Test, used as a covariate for radio check data.
    b. Scores from the Santa Barbara Sense of Direction Scale.

3.7 Data Analysis

Data analyses were performed after the conclusion of the experiment. For the navigation times and radio check response times and durations, a square root transformation was performed before the statistical analysis to give the data a more normal distribution (Bland and Altman, 1996). For the purpose of reporting transformed data, and to make results more understandable to the reader, square root means were squared and then reported. Square root 95% confidence limits were also squared and then reported.

For all dependent variables with interval data (navigation time and radio check response time and duration), data were analyzed separately using separate Linear Mixed Model Analyses (SPSS Version 19). For scores with sufficient degrees of freedom (radio check response time and duration), scores on the perspective taking/spatial orientation test were used as a covariate. For all data, effects showing a p value greater than 0.05 were not considered statistically significant. A least significant difference (LSD) post hoc test was performed on significant effects, and effects showing a p value greater than 0.05 were not considered statistically significant.

For navigation accuracy data, and for questionnaire ratings for comfort, physical effort, and ease of performance, the data were analyzed separately using nonparametric tests. The Independent-Samples Kruskal-Wallis Test was used for navigation accuracy and for the questionnaire comfort and physical effort ratings. The Independent-Samples Chi-Square Test was used to analyze ranked ease of performance. For all questionnaire data, effects showing a p value greater than 0.05 were not considered statistically significant.

4. Results

4.1 Participants

Post-study statistical tests (an SPSS Mixed Linear Model) were performed on the transformed navigation time and radio check time and duration data, using compensation as the only variable, to determine whether there was any significant difference with respect to compensation. Results showed no significant navigation time differences between compensated and uncompensated participants, F (1, 7.541) = 0.400, p = 0.546. There were also no significant differences between compensated and uncompensated participants for radio task response time, F (1,14) = 0.667, p = 0.428, or for radio check duration, F (1,14) = 2.970, p = 0.107. Thus, compensated and uncompensated participants were combined into one group of participants for data analysis.

4.2 Navigation Task Data

4.2.1 Navigation Accuracy

Navigation accuracy data were not available for one participant (participant 16). Results for the remaining 15 participants indicated that there were a total of 11 participant errors in a total of 60 navigation tasks performed (18% of navigation tasks had errors). Almost all navigation errors were wrong turns. An Independent-Samples Kruskal Wallis Test indicated that there was a significant difference ($df = 3, 61$; $H = 9.901$, $p = 0.019$) between the distribution of the number of errors in different environments; six errors occurred in the Computer Monitor environment, four errors in the CAVE, one error in the Warehouse With Load environment, and none in the Warehouse Without Load environment. Thus, there were significantly more navigation errors associated with virtual environments (10 errors in the Computer and the CAVE environments) than with the real (both warehouse) environments (one error). There were no instances in which the participant asked for navigation directions from the experimenter or traffic assistant; thus, it appears that participants preferred to make navigation errors rather than ask for directions.

4.2.2 Navigation Time

The SPSS Linear Mixed Model performed on the transformed navigation time data from navigation trials with no errors indicated a significant main effect for environment, F (3, 25.696) = 15.859, $p < 0.001$. For reporting purposes, the mean navigation times were transformed back into real (non-transformed) units, with means, and upper and lower 95% confidence limits shown in table 1. Figure 9 shows mean navigation time as a function of environment. Post hoc LSD tests indicated that mean navigation time for the CAVE was significantly longer than all other environments and the navigation time for Warehouse Without Load was significantly shorter than all other environments. The Computer Monitor and Warehouse With Load environments were not significantly different from each other ($p = 0.576$); therefore, there was no significant difference between virtual and real environments. The largest difference between means (between the CAVE and the Warehouse Without Load environments) was 1.228 min.

Table 1. Mean navigation times[a] and 95% confidence intervals, as a function of environment.

Environment	Mean Navigation Time (min)	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Warehouse Without Load	10.407 a	10.068	10.752
Warehouse With Load	10.930 b	10.582	11.290
Computer Monitor	11.036 b	10.654	11.424
CAVE	11.635 c	11.256	12.020

[a] Means with different letters are significantly different.

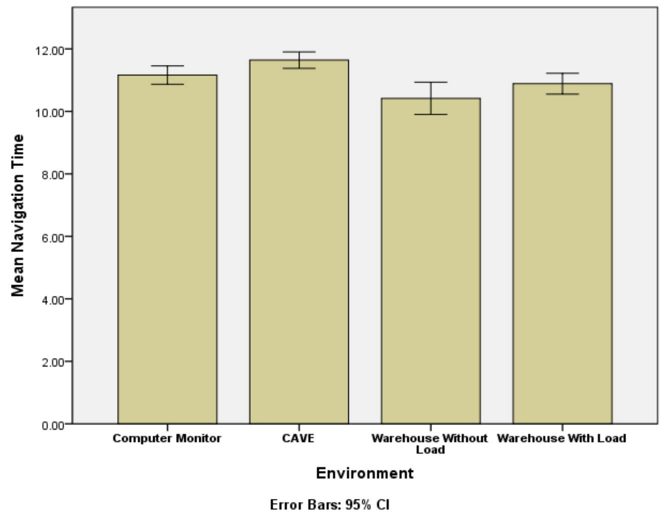

Figure 9. Mean navigation time (in minutes) with 95% confidence intervals, as a function of environment.

4.3 Radio Check Data

4.3.1 Radio Check Accuracy

Results indicated that participant response to target radio check messages was very accurate, showing a total of 25 errors (4%) out of a total of 640 total radio check tasks. Figure 10 shows the types and number of errors for each environment. Nine errors consisted of no participant response to the target call sign, six errors were use of an improper word other than call sign in the radio check response, and four errors concerned the use of an improper call sign in the radio check response. In examining number of errors as a function of environment, a total of 14 errors were made in real environments: 8 in the Warehouse Without Load and 6 in the Warehouse With Load. The remaining 11 errors were made in virtual environments: 9 in the CAVE and 2 at the Computer Monitor. However, a Chi-Square Test indicated that there was no significant difference for number of errors in each environment (df = 3, x^2= 1.372, p = 0.712).

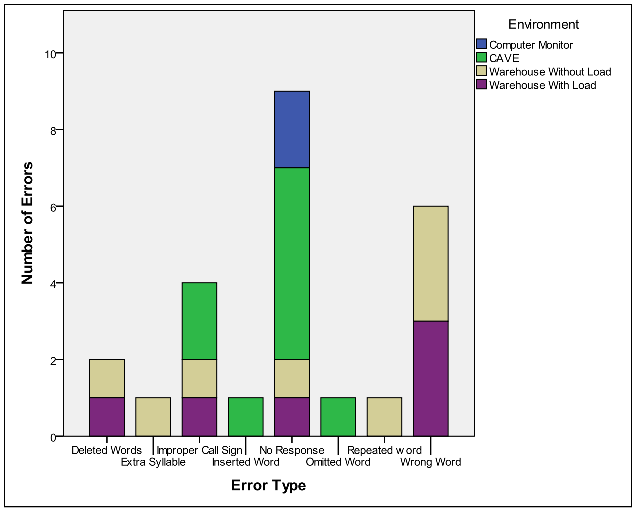

Figure 10. Type and number of errors as a function of environment.

4.3.2 Radio Check Response Time

The SPSS Linear Mixed Model performed on the transformed data, with scores on the perspective taking/spatial orientation test used as a covariate, indicated a significant main effect for environment, $F(3, 563.302) = 13.097$, $p = 0.001$. For reporting purposes, the mean radio check response times transformed back into nontransformed units with means, and upper and lower confidence limits, are shown in table 2. Post hoc LSD tests ($p < 0.001$) indicated that the mean radio check response time for the Warehouse With Load environment was significantly shorter than all other environments. There were no other significant differences. Thus, there was no significant difference in mean response time between the CAVE, Computer Monitor, or Warehouse Without Load environments. The largest significant difference between means (between the CAVE and the Warehouse With Load and environments) was 0.109 sec.

Table 2. Mean radio check response times[a] and 95% confidence intervals, as a function of environment.

Environment	Mean Radio Check Response Time (s)	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Warehouse With Load	5.126 a	5.049	5.203
Warehouse Without Load	5.198 b	5.121	5.276
Computer Monitor	5.189 b	5.117	5.267
CAVE	5.235 b	5.162	5.313

[a]Means with different letters are significantly different.

4.3.3 Radio Check Response Duration

The SPSS Linear Mixed Model performed on the transformed data, with perspective taking/spatial orientation test scores used as a covariate, indicated a significant main effect for environment, F (3, 569.898) = 5.076, $p = 0.002$. The mean radio check task response durations with means and upper and lower confidence limits are shown in table 3. Post hoc LSD tests ($p < 0.05$) indicated that the CAVE response duration was significantly greater than all other environments. Thus, there was no significant difference between the virtual Computer Monitor environment and the real (Warehouse With Load and Warehouse without Load) environments. The largest significant difference between means (between the Computer Monitor and the CAVE environments) was 0.063 sec.

Table 3. Mean radio check response durations[a] and 95% confidence intervals, as a function of environment.

Environment	Mean Radio Check Response Duration (s)	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Computer Monitor	2.729 a	2.544	2.921
Warehouse With Load	2.732 a	2.547	2.924
Warehouse Without Load	2.749 a	2.563	2.941
CAVE	2.792 b	2.605	2.986

[a]Means with different letters are significantly different.

4.4 Final Questionnaire Data

4.4.1 Comfort

An Independent-Samples Kruskal-Wallis test for median comfort rating as a function of radio check and navigation tasks indicated no significant differences for environment (df = 3, 127, H = 4.509, $p > 0.05$), but did report a significant effect for task type (radio check and navigation tasks) (df = 1, 127, H = 4.874, $p = 0.027$). The data showed that the median rank for comfort associated with the radio check task was 70.83, while the median rank for comfort associated with the navigation task was 57.28, indicating that the navigation task had a significantly greater number of lower comfort ratings than did the audio task.

4.4.2 Physical Effort

The Independent-Samples Kruskal-Wallis Test performed on the level of physical effort ratings for navigation tasks indicated that environment was significant (df = 3, 127, H = 44.121, $p < 0.001$). Larger means denote higher levels of perceived physical effort. The Kruskal-Wallis data indicated that mean ranks were 45.69 for CAVE, 50.42 for Computer Monitor, 63.36 for Warehouse Without Load, and 95.95 for Warehouse With Load. Figure 11 shows box plots containing the medians and 95% confidence limits for all environments. The rankings indicated that Warehouse With Load was rated as requiring a significantly higher level of physical effort (p > 0.05) than any other environment. There was no significant difference between the virtual environments.

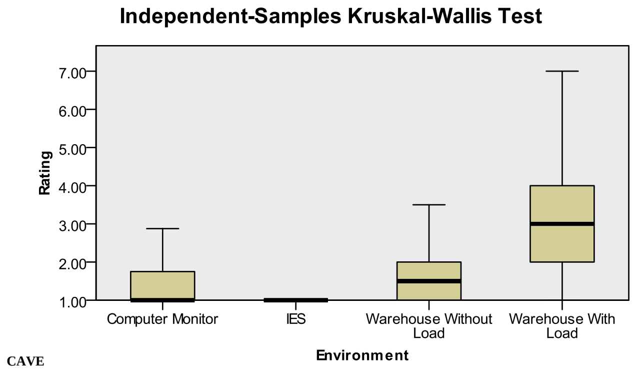

Figure 11. Physical effort questionnaire rating as a function of environment with 95% confidence intervals.

4.4.3 Ranked Ease of Performance for the Navigation Task

To obtain navigation task data, participants were asked to rank each environment for ease of performing the navigation task; a rank of 1 was easiest for navigating, 2 was more difficult, 3 was more difficult than 2, and 4 was the most difficult. A Chi-Square Test performed on the ranking data indicated that there were significant differences in environment rankings ($df = 9$, Pearson $X^2 = 34.143$, $p < 0.005$). As shown in table 4, the Warehouse Without Load environment had the highest number (11) of 1 rankings, indicating the greatest ease of performance. The Computer Monitor environment had the greatest number (7) of 2 rankings. Warehouse Without Load and CAVE each had the greatest number (5) of 3 rankings. The Warehouse With Load environment was ranked fourth (indicating lowest ease of performance) nine times. The data indicated that the Warehouse Without Load was ranked highest for ease of performance while Warehouse with Load was ranked lowest.

Table 4. Count and expected count for ranked ease of navigation task performance in each environment.

Environment		Ranking				Total
		1	2	3	4	
Virtual in CAVE	Count	7	3	5	2	17
	Expected Count	4.75	4.00	4.25	4	17
Computer Monitor	Count	1	7	4	5	17
	Expected Count	4.75	4.00	4.25	4	17
Warehouse Without Load	Count	11	1	5	0	17
	Expected Count	4.75	4.00	4.25	4	17
Warehouse With Load	Count	0	5	3	9	17
	Expected Count	4.75	4.00	4.25	4	17
Total	Count	19	16	17	16	68
	Expected Count	19	16	17.	16	68

4.4.4 Ranked Ease of Performance for the Radio Check Task

To obtain the radio check task data, participants were asked to rank each environment for ease of performing the task; a rank of 1 was easiest, 2 was more difficult, 3 was more difficult than 2, and 4 was the most difficult. A Chi-Square Test performed on ranking data indicated that there were significant differences in environment rankings (*df* = 9, Pearson $X^2 = 37.328$, $p < 0.005$). As shown in table 5, the Warehouse Without Load environment had the highest number (10) of 1 rankings, indicating the greatest ease of performance; the Computer Monitor environment had the greatest number (9) of 2 rankings; Warehouse Without Load had the greatest number (6) of 3 rankings; and the Warehouse With Load environment was ranked fourth (indicating lowest ease of performance) 10 times. The data indicated that the Warehouse without Load was ranked highest for ease of performance and Warehouse With Load was ranked lowest.

Table 5. Count and expected count for ranked ease of radio check task performance in each environment

Environment		**Ranking**				**Total**
		1	2	3	4	
Virtual in CAVE	Count	7	2	4	3	16
	Expected Count	4.538	3.821	3.821	3.820	16
Computer Monitor	Count	1	9	4	3	17
	Expected Count	4.820	4.060	4.060	4.060	17
Warehouse Without Load	Count	10	1	6	0	17
	Expected Count	4.820	4.060	4.060	4.060	17
Warehouse With Load	Count	1	4	2	10	17
	Expected Count	4.820	4.060	4.060	4.060	17
Total	Count	19	16	16	16	68
	Expected Count	19	16	16	16	127.0

5. Discussion

The objective of this study was to develop a characterization of the interaction of physical load and environment on dismounted Soldier performance in navigation and radio check tasks. This characterization was accomplished by exploring the effect of physical load on Soldier performance, investigating the effect of real and virtual environments on Soldier performance, and exploring the potential of radio check response time, duration, and accuracy as measures of dismounted Soldier cognitive performance.

5.1 The Effect of Physical Load on Soldier Performance

It was hypothesized that Soldier performance on navigation and radio check tasks would be negatively correlated with load, and that Soldier performance would show some degradation from the no-load to the 24-kg load environment. Thus, the experimenters expected that performance time means for the 24-kg load environment would be significantly greater than means for the no-load environments.

The results of this study support the hypothesis. Soldier load did have a significant effect on navigation time; navigation time was shorter for navigating the warehouse with no load than for any other condition. Subjective questionnaire data indicated that navigating with a load resulted in higher perceived physical effort and lower ease of performance. Overall, the results indicated that physical load did have a significant, consistent effect on Soldier performance.

For radio check response time, the Warehouse With Load was significantly faster than any other environment. The lack of performance decrement with increased load was explained by Crowell et al. (1999), who suggested that carrying a light load (in that case, 23 kg) might cause an exercise-induced increase in alertness, which could result in improved performance of a monitoring task. The data from this study also agree with the results of studies reviewed by Tomporowski (2003), who found that acute bouts of exercise can facilitate response speed and accuracy.

5.2 The Effect of Real and Virtual Environments on Soldier Cognitive and Physical Performance

It was hypothesized that navigation in both virtual environments (CAVE and Computer Monitor) would require more time and attention than navigation in both real environments (Warehouse With Load and the Warehouse Without Load). Thus, it was expected that means for the virtual environments would be significantly greater than means for the real-world environments.

Overall, the quantitative data showed that real and virtual environments had a significant effect on navigation time. It took Soldiers longer to navigate in both of the virtual environments than to walk around the warehouses without load. This is also reflected in the rankings for ease of performance of the navigation task. Soldiers ranked the virtual environments lower than the Warehouse Without Load condition. In addition, the navigation time in the CAVE was significantly longer than at the computer monitor. Similarly, environment had a significant effect on navigation accuracy. Significantly more errors occurred in the virtual environment than the real environment. This is similar to the result found by Schmelter et al. (2009) for subjects trained to navigate a maze. Subjects who navigated the virtual maze made more mistakes than those who navigated the real maze. In contrast to the results for the navigation task, environment affects only part of the radio check task. Environment affects response duration but not response accuracy or response time. The response duration is longer in the CAVE than any of the environments.

The lagging CAVE performance in the navigation time and radio check duration tasks may partially be explained by Klein (1976), who suggested that "moving per se does not always require attention, rather it is the guidance of movement, in terms of direction and speed that requires attention." It could be possible that the guidance of movement (using a joystick) was more cognitively demanding in the CAVE, and that the extent to which movement itself, or the need to attend to virtual movement, imposed a cognitive demand that was greater than that required by the warehouse environments. However, Klein's suggestion does not explain why CAVE navigation time and radio check duration were significantly longer than those for the Computer Monitor environment, in which Soldiers also used a joystick to guide movement. Future research should be conducted to explain this discrepancy.

5.3 The Potential of Radio Check Response Time, Duration, and Accuracy as Measures of Dismounted Soldier Cognitive Performance

Because of the relationship between cognitive performance and speech measures, it was hypothesized that radio check response time, duration, and accuracy would have the potential for reflecting meaningful differences in Soldier performance.

Response accuracy can be used as a measure of cognitive performance because it is not affected by the load carried or the environment. Response time and response duration can also be used as measures of cognitive performance provided two limitations are taken into consideration: (1) response time is shorter when subjects carry a load and (2) response duration in the CAVE is longer than in the other environments. Therefore, accuracy, response time, and response duration can be used as metrics of cognitive performance provided that (1) response time results are not compared if the load carried was different and (2) results for response duration are not compared between the CAVE environment and any other environment.

The results of this study showed several significant differences for radio check response time and response duration means, although differences between the highest and lowest means were often tenths of seconds. However, response times and durations of this nature may have practical as well as statistical significance. In modern missions, dismounted Soldiers are required to perform tasks in threatening or ambiguous environments (e.g., patrolling potentially hostile city streets to detect dismounted enemy snipers). In these environments, decisions to react (for example, whether an object just spotted could be a friendly ally or an unfriendly enemy target) must be made in very short periods of time. Because Soldier decision time may need to be very short, the mean radio check response times and durations may have practical significance for the dismounted Soldier.

6. Conclusions and Recommendations

In short, results from this research indicated that physical load and environment each affect navigation and responses to a radio check task. For the conditions in this study, carrying a load increased navigation time but decreased response time for the radio check task. With regard to the environment in which an experiment is conducted, more navigation mistakes occurred in the virtual environment than in the real environment. In addition, navigating in the CAVE takes longer than in the other environments (real world and Computer Monitor). Responses to the radio check task are also longer in the CAVE than in the other environments.

Three different recommendations can be made based on the results of this study:

- Explore the effect of heavier loads on soldier performance. Results from this study indicated that physical exertion, specifically the weight of the rucksack, had a discernible effect on Soldier physical and cognitive performance. The load used in this study was a relatively light fighting load of 24 kg packed inside a U.S. Army rucksack. In addition, the navigation task was relatively simple, involving a short (approximately 10-min) walking-paced task performed upon predominately level concrete roads. However, the 24-kg load does not represent the load that the dismounted Soldier must often carry in battlefield environments. Bleidel (2011) observed that Soldiers often perform tasks while carrying heavy loads (about 130 lb) for several hours. Researchers using heavy loads such as these (May et al., 2009) found that carriage load disrupted balance control and degraded both cognitive processes and situational awareness. Future research should involve more realistic criteria, including greater carriage loads and longer task times, to determine the effect of physical load on Soldier performance.

- Use additional radio check task metrics to measure Soldier cognitive performance. The radio check task used in this study was developed to measure the effects of cognitive load on Soldier speech. Response time, duration, and accuracy are measures of speech fluency and speech rate, which are affected by auditory cognitive and attentional demands (Scherer et al., 2002). The results from this study indicated that radio check response accuracy can be a useful metric of Soldier cognitive performance. Response time and duration can also be used to assess cognitive performance if comparisons between conditions are made only when load is constant and when the results for the CAVE environment are not compared to the results from other environments. However, additional radio check metrics have been suggested; Scherer et al. (2002) noted that fundamental frequency, speech energy contours, and spectral parameters can also be used as speech metrics. Therefore, future studies should include these metrics.

- Explain performance differences found between the CAVE and other environments. Soldier performance in the radio check and navigation tasks indicated that performance in the CAVE lagged behind that of the real-world warehouse environments and sometimes behind the Computer Monitor environment. This may have been due to some factor in the simulation. By definition, a simulation in some way always deviates from the real world. However, the deviation from reality means that some aspects of the simulation may not transfer to the real world, and these dissimilarities might affect some aspect of human performance. Philip et al. (2005) found that reaction times were slower during a simulated driving task than in the real world. Bishop and Rohrmann (2003) also found that even detailed computer simulations do not necessarily generate the same quantitative or subjective responses as the corresponding real-world urban environment. It is recommended that future research be conducted to determine precisely why the virtual CAVE had a more detrimental effect on Soldier performance than did the Warehouse With Load environment.

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Appendix A. Participant Informed Consent Form

This appendix appears in its original form, without editorial change.

Consent Form
Army Research Laboratory, Human Research & Engineering Directorate
Aberdeen Proving Ground, MD 21005

Title of Project: Measures of the Ability of Simulated Environments to Replicate Effects of Physical and Cognitive Stress

Project Number: ARL-11-041

Sponsor: Army Research Laboratory

Principal Investigator: Ellen C. Haas
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You are being asked to join a research study. This consent form explains the research study and your part in it. Please read this form carefully before you decide to take part. You can take as much time as you need. Please ask the research staff any questions at any time about anything you do not understand. You are a volunteer. If you join the study, you can change your mind later. You can decide not to take part now or you can quit at any time later on.

Location of the Study

Aberdeen Proving Ground, MD, Building 518.

Purpose of the Study

The purpose of this study is to determine whether cognitive tasks and physiological load affects user performance in a map navigation task.

Procedures to be Followed

You will be exposed to four different experimental conditions in which you will perform a navigation task using a map. At the same time, you will listen for auditory call signs and respond when your particular call sign is given. At the end of the experiment, you will be given a final questionnaire in which you can give comments on the call sign task, and the ease of use of performing each task. You can have a break between each task.

Tasks/Training Before the Study Begins:

First, we will ask you about your medical status (any injuries or illnesses). Next, we will perform a Snellen eye test in which we will check your vision to make sure that it is normal (20:30 vision, which can include wearing corrective lenses, such as i.e., eyeglasses or contact lenses). You may not participate in this study if you have an illness or injury that would affect your ability to see or hear, or have vision that does not fulfill the 20:30 vision criteria.

Next, you will fill out a demographic questionnaire that asks about your gender, age, and military service (if applicable), as well about other personal characteristics. Next, you will fill out a computer questionnaire that asks about your computer experience (number of hours spent on a computer, computer games that you play). After that, you will fill out two questionnaires that ask about your spatial ability.

After this, you will perform experimental trials. Prior to each experimental condition, we will show you how to perform the call sign and the navigation task, and, if applicable, the computer task used in that condition.

Experimental Trials: After pre-experimental training is over for that condition, you will perform four experimental conditions; 1) Using a map to navigate (walking) around ARL warehouses while wearing no physical load; 2) Using a map to navigate(walking) around ARL warehouses while wearing a fighting load 53 lbs (simulated by using weights contained in a backpack worn on the your back; 3) In Bldg. 518, using a map and joystick to navigate (sitting) around a computerized version of the warehouse, as shown on a computer monitor in Bldg. 518, and 4) Using a map and joystick to navigate (sitting) through a virtual warehouse environment viewed on four screens of the Immersive Environment Simulator (IES). During the tasks in Bldg. 518, your travel speed will be capped at 4.0 mph. During each of these tasks, you will listen to military call signs played on audio MP3 players, and will verbally respond when you hear your call sign.

After the trials are over, you will be asked to fill in another questionnaire that deals with how you felt about navigating in each environment.

Duration (Time Required)

The study will require approximately 4 hours of your time over a 1 day period. Participants from A-Team Solutions will require an additional 30 minutes for pick-up and drop-off at the APG Burger King meeting site.

Compensation for Participation

You cannot be paid if you are a member of the military, a civilian employee of the U. S. Government, or a family member of an employee of the Human Research & Engineering Directorate.

Non-government civilian participants will be reimbursed for their time at a rate of $30 per hour. Participants dismissed early (due to voluntary withdrawal or dismissal) will be paid commensurate with the time completed at a minimum of one half-hour compensation. If you are working for a temporary agency, you will be paid directly by that agency. Payment forms are completed for each monetary disbursement that provide data about the volunteer to the Defense Finance and Accounting Office (DFAS).

Risks

The investigators will monitor the safety of the volunteers in the study; however, not all risks or discomforts can be eliminated. Risks and discomforts include those commonly associated with using computer joystick controls, such as fatigue.

Benefits

Your vision will be checked for free, and you may feel satisfaction for participating in a study to identify the most appropriate environment for specific types of dismounted Soldier research.

Confidentiality

Your participation in this research is confidential. The data will be stored and secured at Aberdeen Proving Ground, in a locked file cabinet. The data, without any identifying information, will be transferred to a password-protected computer for data analysis. After the data is put in the computer file, any paper copies of the data will be shredded. This consent form will be retained by the principal investigator for three years.

If the results of the experiment are published or presented to anyone, no personally identifiable information will be shared. Publication of the results of this study in a journal or technical report, or presentation at a meeting, will not reveal personally identifiable information. The research staff will protect your data from disclosure to people not connected with the study. However, complete confidentiality cannot be guaranteed because officials of the U. S. Army Human Research Protections Office and the Army Research Laboratory's Institutional Review Board are permitted by law to inspect the records obtained in this study to insure compliance with laws and regulations covering experiments using human subjects.

We would like your permission to record your voice during the experimental session. Recordings of your voice will be used in data analysis of response time of your speech commands, and will not be played at any public event. If we cannot record your voice, you cannot take part in this study. Please indicate below if you will agree to allow us to take pictures of you and record your voice.

I give consent have my voice recorded during this study: ___Yes ___No Please initial:____

Contact Information for Additional Questions

You have the right to obtain answers to any questions you might have about this research both while you take part in the study and after you leave the research site. Please contact anyone listed at the top of the first page of this consent form for more information about this study. You may also contact the Chairperson of the Human Research & Engineering Directorate, Institution Review Board, at (410) 278-5992 with questions, complaints, or concerns about this research, or if you feel this study has harmed you. The Chairperson can also answer questions about your rights as a research participant. You may also call the Chairperson's number if you cannot reach the research team or wish to talk to someone else.

Voluntary Participation

Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawal from this study will involve no penalty or loss of benefits you would receive by staying in it.

Military personnel cannot be punished under the Uniform Code of Military Justice for choosing not to take part in or withdrawing from this study, and cannot receive administrative sanctions for choosing not to participate. Civilian or contractor personnel cannot receive administrative sanctions for choosing not to participate in or withdrawing from this study.

You must be 18 years of age or older to take part in this research study. If you agree to take part in this research study based on the information outlined above, please sign your name and indicate the date below.

You will be given a copy of this consent form for your records.

This consent form will be stored by the Principal Investigator in a locked file cabinet for a minimum of three years. Then it will be shredded.

This consent form is approved from 7/9/2012 to 7/9/2013.

Do not sign after the expiration date of 7/9/2013.

____ ____________________
Participant's Signature Date

____
Participant's Printed Name

____ ____________________
Signature of Person Obtaining Consent Date

____
Printed Name of Person Obtaining Consent

Appendix B. Participant Data Form

This appendix appears in its original form, without editorial change.

Questionnaire 1: Subject Data Form

Participant ID____________ Age: _______________

Gender_______________

If Military: MOS:_______________ Rank __________

Years of Experience:________________________

Do you have prior military service? Yes No

If Yes, how long __________

Health Screening Data:

1. Do you have any hearing problems such as ringing or buzzing in your ears? Yes No

2. Do you currently have an ear infection? Yes No

3. Do you have any vision problems? Yes No

   If so, what are they? ____________________________________

4. Do you wear glasses when working on the computer? Yes No

   If YES, did you bring your glasses with you today? Yes No

5. How many hours of sleep did you get last night? ______ hours

6. Are you in your usual state of health physically? Yes No

   If NO, please briefly explain:

Questionnaire 2:

Computer Use Questions:

1. How many hours per week do you use a computer at home and at work? ________

2. How many years have you used a computer? ________

3. Which of the following best describes your expertise with computer? (check √ one)
   _____ Novice
   _____ Good with one type of software package (such as word processing or slides)
   _____ Good with several software packages
   _____ Can program in one language and use several software packages
   _____ Can program in several languages and use several software packages

4. How often do you play video games? (Circle one)

Never   Rarely   Once Every Few Months   Monthly   Daily

5. If you do play video games at least once every few months, which games do you most often play?

6. Have you ever used a joystick when playing video games? Yes No

7. If you have used a joystick, how many years have you used one? ______

8. Do you consider yourself to be good at working with your hands? For example, good at woodworking or sewing? Yes No

9. Do you consider yourself to have good hand-eye coordination? Yes No

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Appendix C. Santa Barbara Sense-of-Direction Scale

This appendix appears in its original form, without editorial change.

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle “1” if you strongly agree that the statement applies to you, “7” if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

1. I am very good at giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for where I left things.

strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.

strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My "sense of direction" is very good.

strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).

strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.

strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

9. I am very good at reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.

strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.

strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips.

strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.

strongly agree 1 2 3 4 5 6 7 strongly disagree

15. I don't have a very good "mental map" of my environment.

strongly agree 1 2 3 4 5 6 7 strongly disagree

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Appendix D. Perspective Taking/Spatial Orientation Test

This appendix appears in its original form, without editorial change.

This is a test of your ability to imagine different perspectives or orientations in space. On each of the following pages you will see a picture of an array of objects and an "arrow circle" with a question about the direction between some of the objects. For the question on each page, you should imagine that you are standing at one object in the array (which will be named in the center of the circle) and facing another object, named at the top of the circle. Your task is to draw an arrow from the center object showing the direction to a third object from this facing orientation.

Look at the sample item on the next page. In this item you are asked to imagine that you are standing at the flower, which is named in the center of the circle, and facing the tree, which is named at the top of the circle. Your task is to draw an arrow pointing to the cat. In the sample item this arrow has been drawn for you. In the test items, your task is to draw this arrow. Can you see that if you were at the flower facing the tree, the cat would be in this direction? Please ask the experimenter now if you have any questions about what you are required to do.

There are 12 items in this test, one on each page. For each item, the array of objects is shown at the top of the page and the arrow circle is shown at the bottom. Please do not pick up or turn the test book- let, and do not make any marks on the maps. Try to mark the correct directions but do not spend too much time on any one question.

You will have 5 minutes for this test.

1. Imagine you are standing at the **car** and facing the **traffic light**.
Point to the **stop sign**.

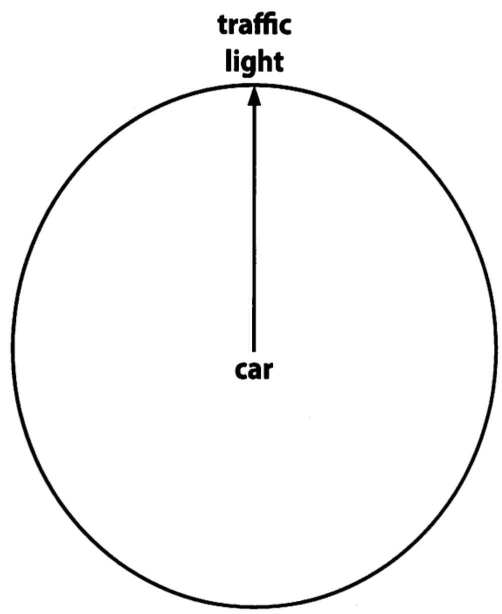

Figure D-1. Perspective and Orientation Test Number 1.

2. Imagine you are standing at the **cat** and facing the **tree**.
Point to the **car**.

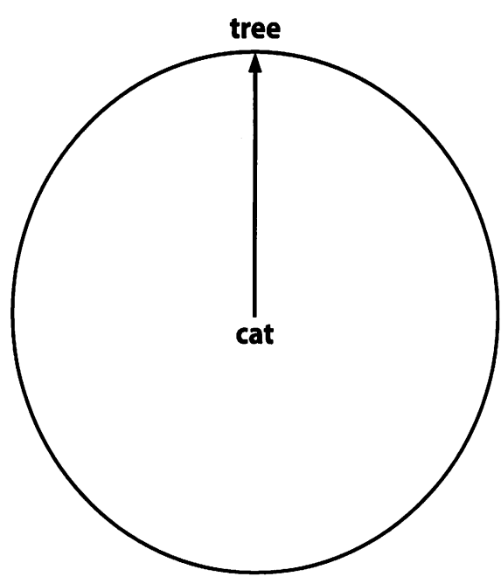

Figure D-2. Perspective and Orientation Test Number 2.

3. Imagine you are standing at the **stop sign** and facing the **cat**. Point to the **house**.

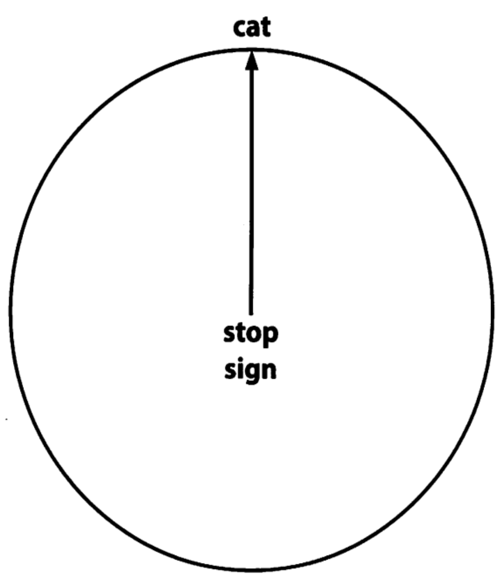

Figure D-3. Perspective and Orientation Test Number 3.

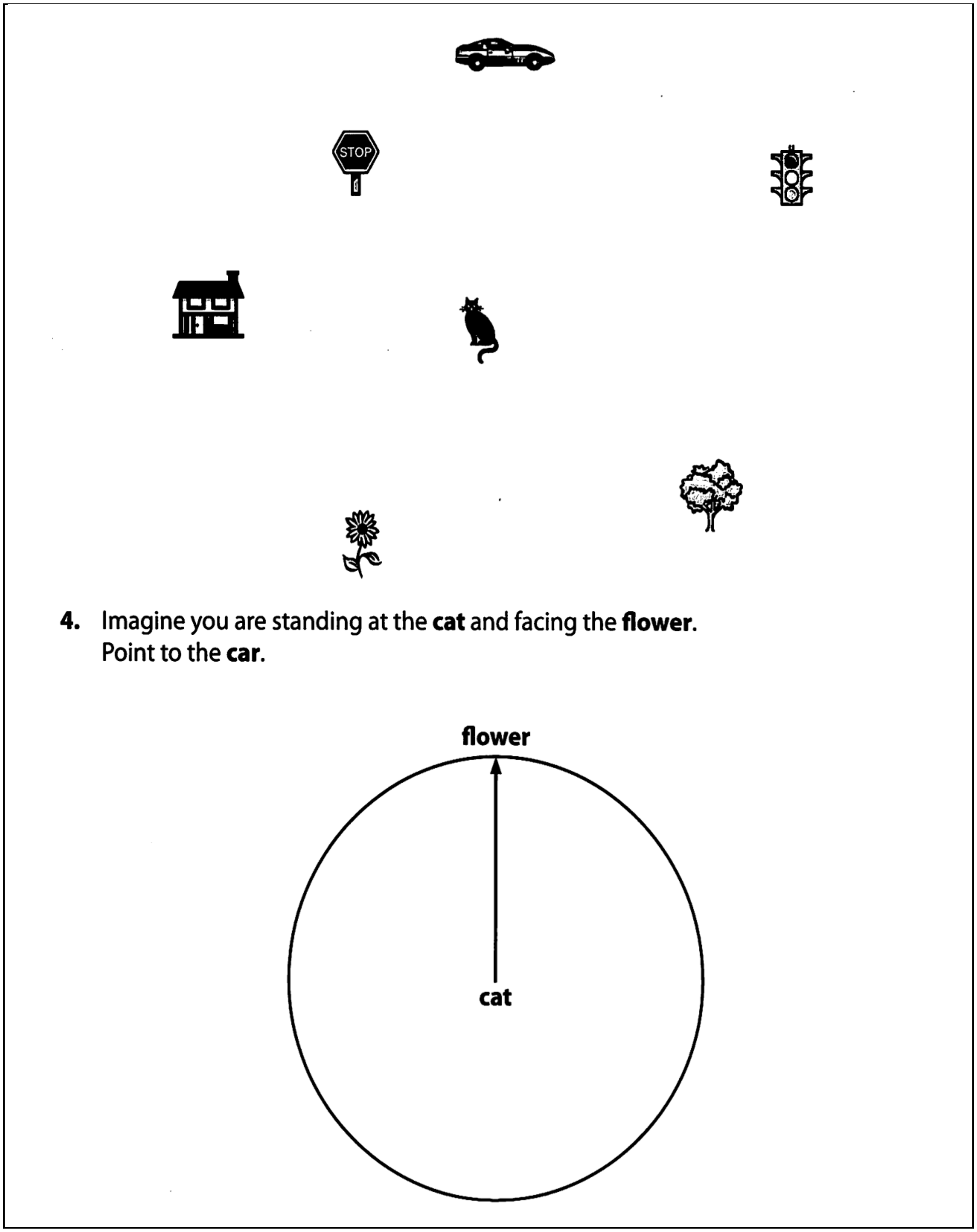

Figure D-4. Perspective and Orientation Test Number 4.

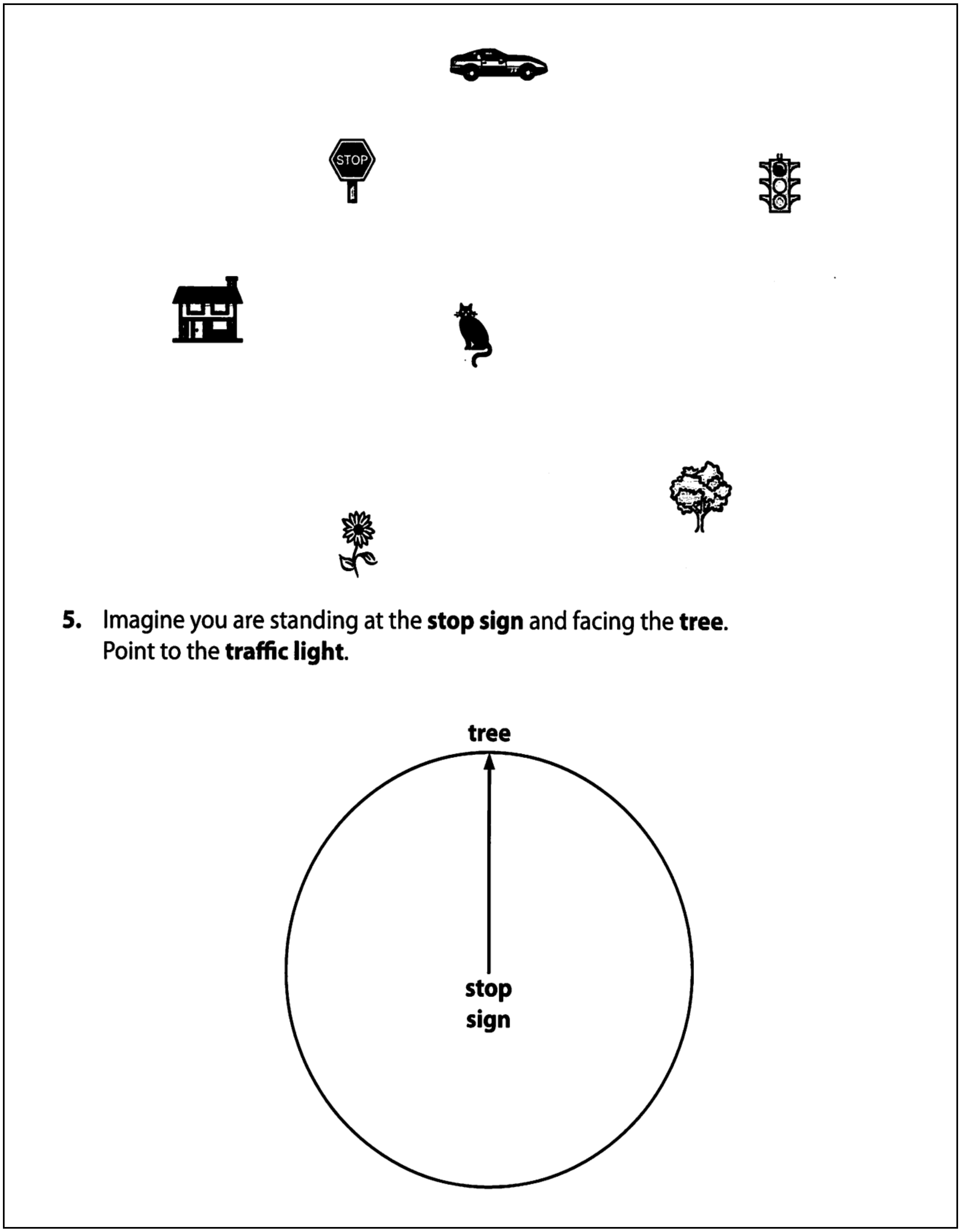

Figure D-5. Perspective and Orientation Test Number 5.

6. Imagine you are standing at the **stop sign** and facing the **flower**. Point to the **car**.

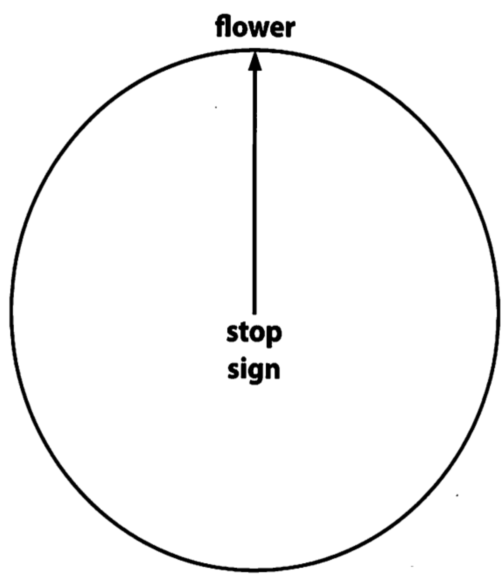

Figure D-6. Perspective and Orientation Test Number 6.

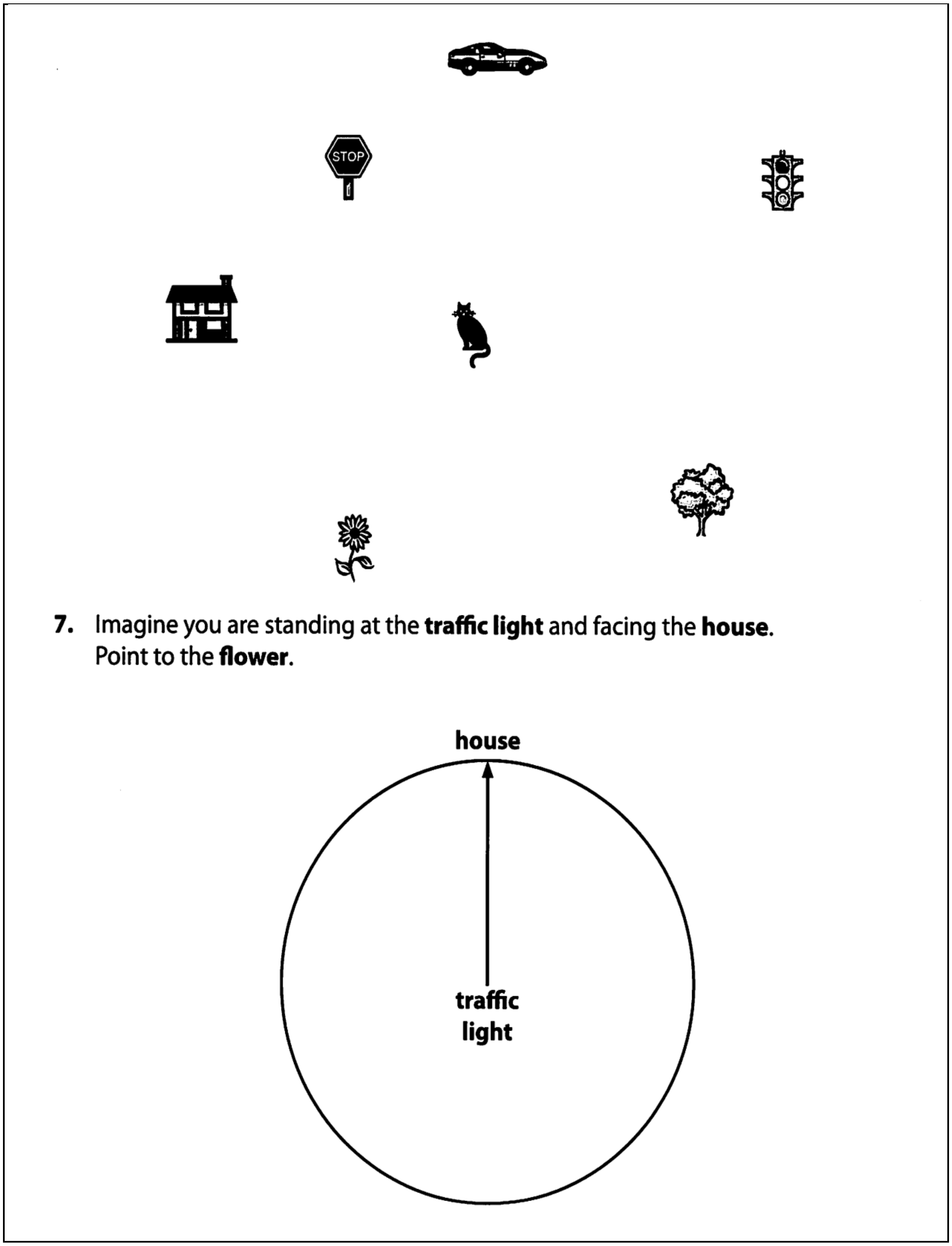

Figure D-7. Perspective and Orientation Test Number 7.

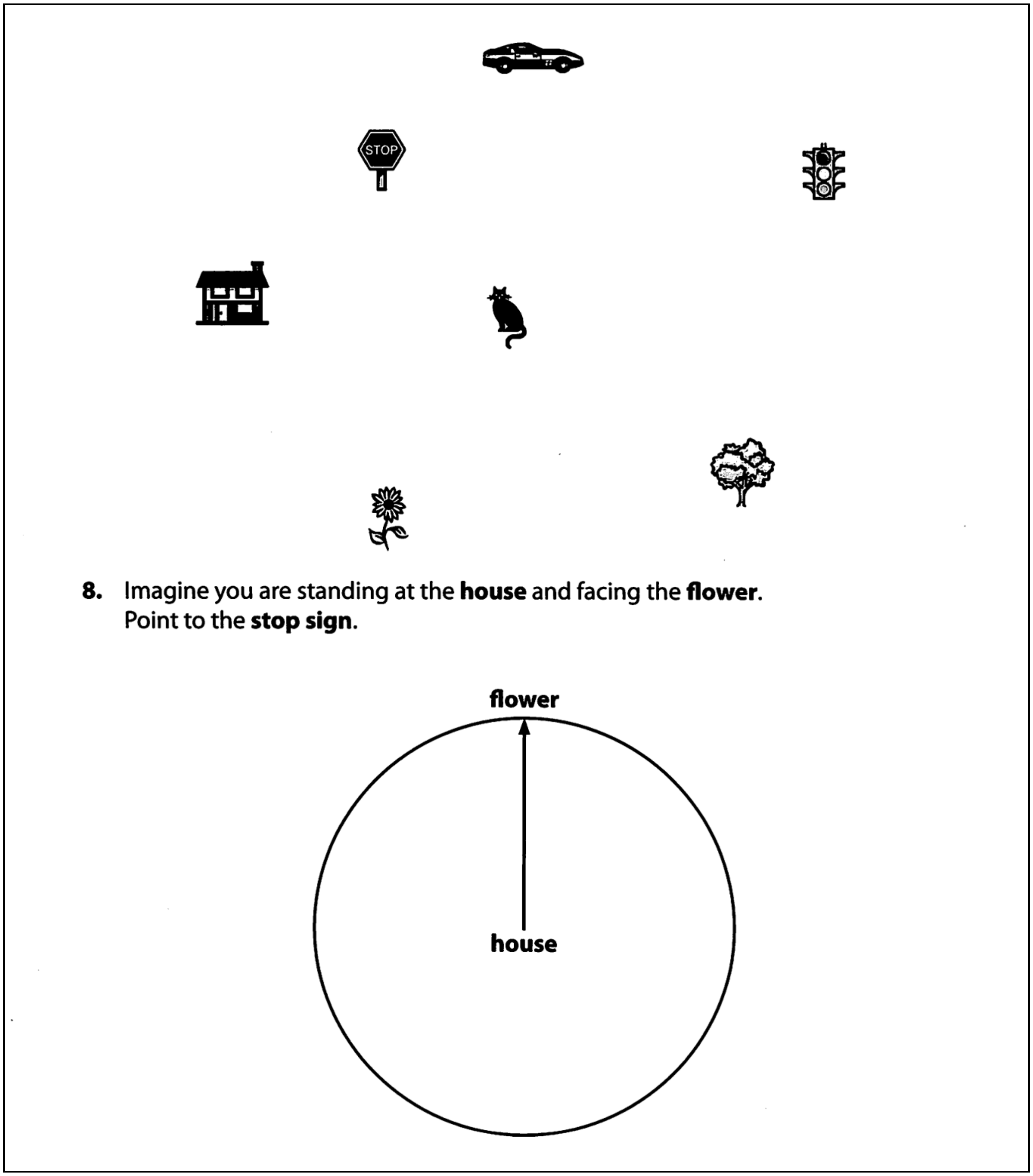

Figure D-8. Perspective and Orientation Test Number 8.

9. Imagine you are standing at the **car** and facing the **stop sign**.
Point to the **tree**.

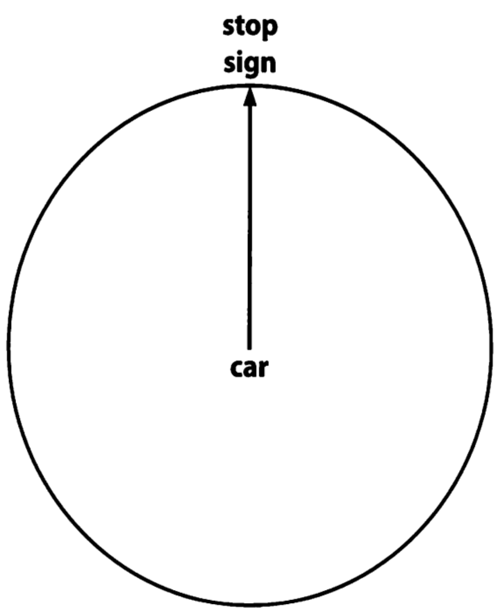

Figure D-9. Perspective and Orientation Test Number 9.

10. Imagine you are standing at the **traffic light** and facing the **cat**.
Point to the **car**.

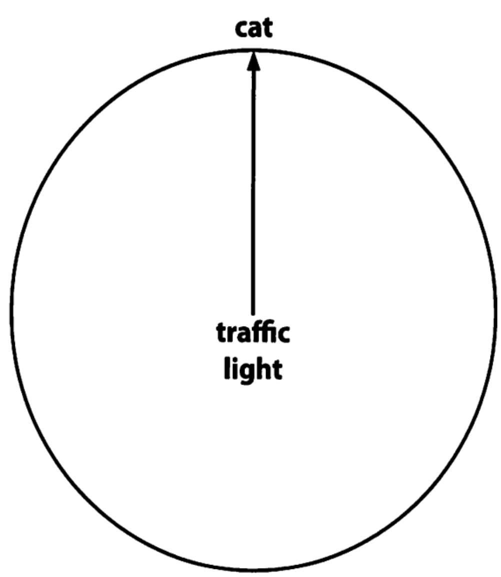

Figure D-10. Perspective and Orientation Test Number 10.

11. Imagine you are standing at the **tree** and facing the **flower**.
Point to the **house**.

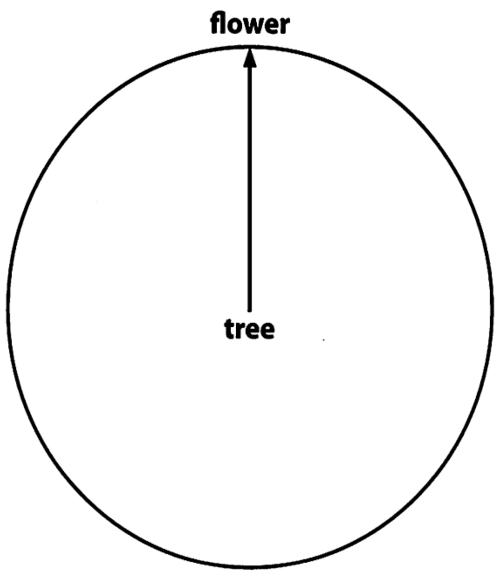

Figure D-11. Perspective and Orientation Test Number 11.

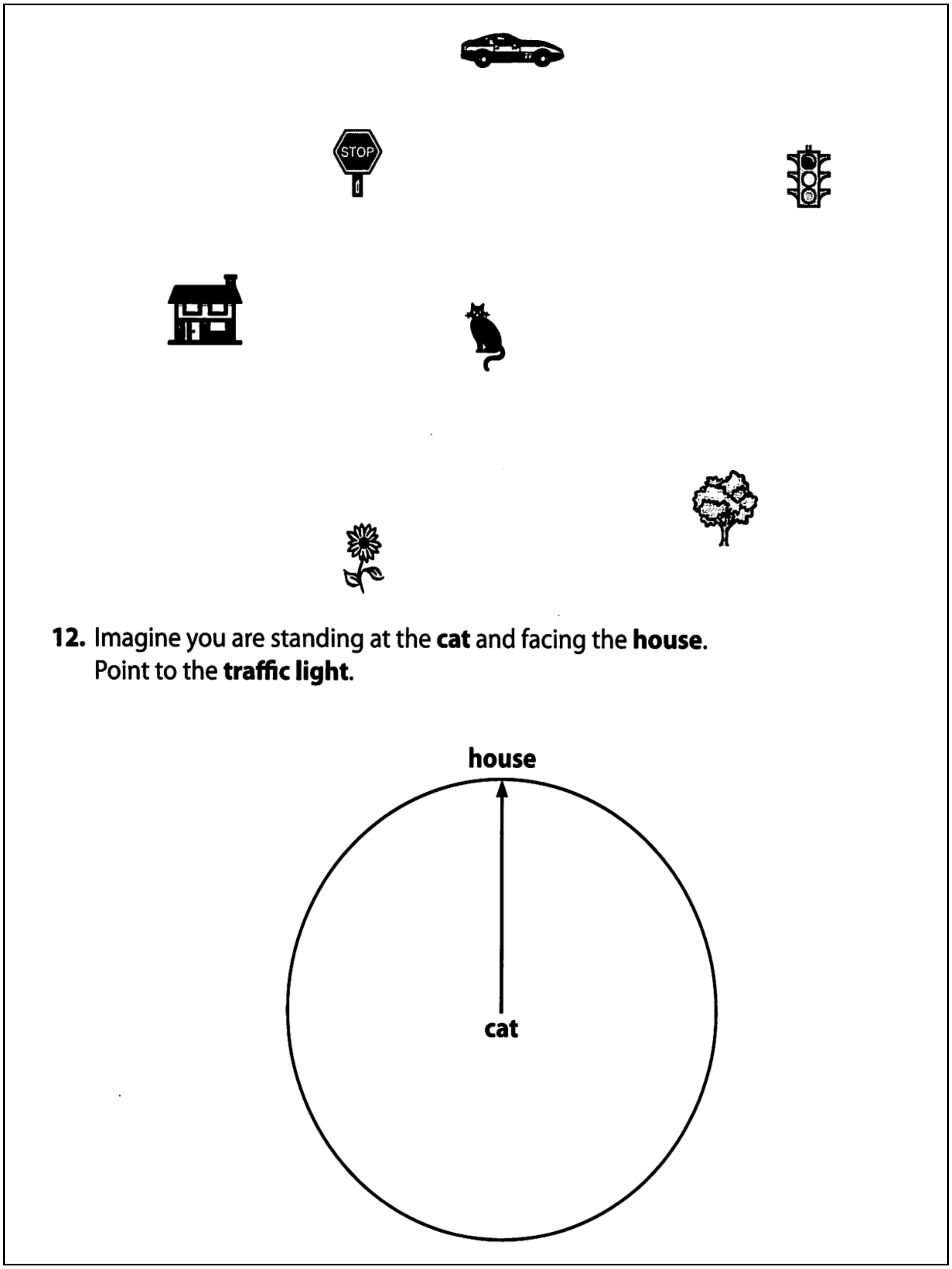

Figure D-12. Perspective and Orientation Test Number 12.

Appendix E. Final Questionnaire

This appendix appears in its original form, without editorial change.

a. Final Questionnaire - Navigation

1. Use the scale below to rate your LEVEL OF COMFORT in each environment: (*write the appropriate number in the box beneath the corresponding environment*):

Scale

Very uncomfortable 1	Uncomfortable 2	Slightly Uncomfortable 3	Neutral 4	Slightly Comfortable 5	Comfortable 6	Very Comfortable 7

Navigating around Warehouse with no-load	**Navigating around Warehouse with 53-lb load**	**Navigating using Computer Monitor and Joystick**	**Navigating in IES using Joystick**
—	—	—	—

2. Use the scale below and rate the PHYSICAL EFFORT REQUIRED to perform the following *conditions (write the appropriate number in the box beneath the corresponding environment)*:

Scale

Very, Very Light 1	Very Light 2	Fairly Light 3	Somewhat Hard 4	Hard 5	Very Hard 6	Very, Very Hard 7

Navigating Around Warehouse with No-load	**Navigating Around Warehouse With 53-lb load**	**Navigating using Computer Monitor and Joystick**	**Navigating in IES using Joystick**
—	—	—	—

3. Use the scale below and rate the how hard or easy it was to do the NAVIGATION TASKS in each *environment (write the appropriate number in the box beneath the corresponding environment)*:

Scale

Very, Very Hard 1	Very Hard 2	Hard 3	Somewhat Easy 4	Easy 5	Very easy 6	Very, Very Easy 7

Navigating Around Warehouse With No-load	**Navigating Around Warehouse With 53-lb load**	**Navigating Using Computer Monitor and Joystick**	**Navigating in IES using Joystick**
—	—	—	0151

4. In each pair of environments (across each row), please circle the environment in which it was easier to perform the navigation task:

Warehouse, no-load	Warehouse, with 53 lb. load
Warehouse, with 53 lb. load	Computer workstation using joystick
Computer workstation with joystick	IES with joystick
IES with joystick	Warehouse, with 53 lb. load
Warehouse, no-load	IES with joystick
Computer workstation using joystick	Warehouse, no-load

5. For each of the tasks below, rate which environment was easiest perform the navigation task, and which was most difficult. Use the numbers 1 through 4, where 1 is the easiest for navigating, 2 was more difficult than 1, 3 was more difficult than 2, and 4 was the most difficult for navigating. Use all numbers and put a different number in each box:

Task	Rating
Navigation task around warehouses with no-load	—
Navigation task around warehouses with 53-lb load	—
Navigation task while using the computer monitor, using a joystick	—
Navigation task while in the IES, using a joystick	—

b. Final Questionnaire - Auditory Monitoring Task

1. Use the scale below to rate your LEVEL OF COMFORT in each environment: *(write the appropriate number in the box beneath the corresponding environment)*:

Scale

Very Uncomfortable 1	Uncomfortable 2	Slightly Uncomfortable 3	Neutral 4	Slightly Comfortable 5	Comfortable 6	Very Comfortable 7

Auditory Task Around Warehouse With No-load	**Auditory Task Around Warehouse With 53-lb load**	**Auditory Task using Computer Monitor and Joystick**	**Auditory Task in IES using Joystick**
—	—	—	—

2. Use the scale below and rate the PHYSICAL EFFORT REQUIRED to perform the following conditions *(write the appropriate number in the box beneath the corresponding environment)*:

Scale

Very, Very Light 1	Very Light 2	Fairly Light 3	Somewhat Hard 4	Hard 5	Very Hard 6	Very, very Hard 7

Auditory Task around Warehouse with No-load	**Auditory Task Around Warehouse With 53-lb load**	**Auditory Task Using Computer Monitor and Joystick**	**Auditory Task in IES Using Joystick**
—	—	—	—

3. Use the scale below and rate the how hard or easy it was to do the AUDITORY TASK in each environment *(write the appropriate number in the box beneath the corresponding environment):*

Scale

Very, Very Hard 1	Very Hard 2	Hard 3	Somewhat Easy 4	Easy 5	Very Easy 6	Very, Very Easy 7

Auditory Task Around Warehouse With No-load	**Auditory Task Around Warehouse With 53-lb Load**	**Auditory Task Using Computer Monitor and Joystick**	**Auditory Task In IES Using Joystick**
—	—	—	—

4. In each pair of environments, please circle the environment in which it was easier to perform the auditory task:

Warehouse, no-load	Warehouse, with 53 lb. load
Warehouse, with 53 lb. load	Computer workstation using joystick
Computer workstation with joystick	IES with joystick
IES with joystick	Warehouse, with 53 lb. load
Warehouse, no-load	IES with joystick
Computer workstation using joystick	Warehouse, no-load

5. For each of the tasks below, rate which environment was easiest perform the auditory task, and which was most difficult. Use the numbers 1 through 4, where 1 is the easiest for performing the auditory task, 2 was more difficult than 1, 3 was more difficult than 2, and 4 was the most difficult for performing the auditory task. Use all numbers and put a different number in each box:

Task	Rating
Auditory task around warehouses with no-load	__
Auditory task around warehouses with 53-lb load	__
Auditory task while using the computer monitor, using a joystick	__
Auditory task while in the IES, using a joystick	__

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