# The impact of Night Vision Goggles on wayfinding performance and the acquisition of spatial knowledge

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Abstract

The experiments of this thesis examined the effects of Night Vision Goggles (NVGs) on navigation and wayfinding performance and the acquisition of spatial knowledge. Findings show that navigation and wayfinding with NVGs (experimental group) appeared to be harder, with longer navigation times and more navigational steps and errors compared to not using NVGs (control group). Moreover, a significant decrease in navigation times over the course of the wayfinding trials occurred earlier with NVGs, in addition to significant decreases in navigational steps compared to the control group. The impact of NVGs was also evident in spatial memory tasks. Relative direction pointing to searched objects (targets) across rooms and to distracters in the same room was better for those who performed the search without NVGs compared to using NVGs. In a map drawing task, participants in the NVG group were more likely to position more objects incorrectly, receive worst map goodness scores and draw an extra room compared to controls. The findings are discussed in terms of the impact of NVGs on wayfinding performance and the acquisition of spatial knowledge in spatial cognition. In addition, some practical implications regarding the use of night vision devices are discussed.

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## Introduction

### *Background and Overview*

How do we know where we are? How do we learn to find our way around in everyday life, particularly in a novel environment? How critical is the role of vision in this? Much research has been devoted to investigating and understanding human spatial cognition - that is, the acquisition and use of knowledge about space - and the factors that may influence it.

Two types of spatial abilities, navigation and orientation, are involved in moving through the environment. Navigation is the process of moving from one point to another in a particular environment (Parush & Berman, 2004; Darken, Allard & Achille, 1998). Navigation consists of two components: locomotion and wayfinding (Montello, in press; Roberts, Parush & Lingaard, in press; Darken & Peterson, 2002). Locomotion is the movement of one's body in order to get from one place to another. Wayfinding is a goal-directed and planned movement of one's body in an environment in an efficient manner and includes the ability to find specific locations and recognizing destinations when reached (Montello, in press; Roberts et al, in press; Darken & Peterson, 2002). Orientation requires the knowledge of where one is relative to elements and cues in an environment and the continuous updating of this knowledge (Parush & Berman, 2004; Montello, in press; Wang & Spelke, 2002). Our ability to find our way or navigate successfully, especially when the destination is not immediately visible, involves navigating through body movement and planning effective routes as well as updating one's position and orientation during travel.

It has been suggested that the ability to navigate and orient requires forming mental representations of the environment (Thorndyke & Hayes-Roth, 1982; Wang & Spelke, 2000). Such representations consist of the knowledge of spatial relations between objects and places in the environment (Loomis, et al., 1993; Klatzky, 1998; Waller, Loomis, Golledge, & Beall, 2000). Tolman (1948) suggested that this representation could be considered as a "cognitive map" of the environment. The acquisition of this mental representation of spatial knowledge, or cognitive map, has been shown to occur by direct environmental exposure through active navigation and exploration (Gallistel, 1990; Thorndyke & Hayes-Roth, 1982; McNamara, 1986; McNamara, Ratcliff, & McKoon, 1984). In addition, spatial knowledge can also be acquired indirectly by learning the environment from a map or route description (Thorndyke & Hayes-Roth, 1982; McNamara, 1986).

While successful navigation involves integrating information from several sensory and motor systems (e.g. visual, tactile, auditory), visual information is thought to be a central cue (Montello, in press; Riecke, 2003). The experiments of this thesis will examine the effects of less-than-optimal visual conditions on the acquisition and use of spatial knowledge. Specifically, it is intended to examine how the use of Night Vision Goggles (NVGs), a device for enhancing vision at low light levels, may influence the acquisition and update of spatial information that is used to form mental representations through active navigation and exploration. Visual conditions using NVGs are less optimal than full daylight and provide a variety of visual decrements (e.g., restricted Field

Of View - FOV, lower resolution, hyperstereopsis, etc.) and may impact the capacity to acquire and utilize spatial knowledge.

The standard approach towards these studies has been to characterize their impact on visual performance in the laboratory and the operational setting. The thrust of these studies has been to better understand how NVGs affect our visual perception. These studies have shown slight decrements in visual performance when using NVGs (Jennings & Craig, 2000; Vyrnwy-Jones, 2001; Sheehy & Wilkinson, 1989; Reising & Martin, 1995; Niall, Reising, & Martin, 1999). One might consider such a visual environment as impaired or possibly "degraded" relative to normal day vision, while significantly enhanced in comparison to unaided night vision (Johnson, 2004). In the context of the current thesis, I shall consider the visual imagery produced by NVGs as a visually degraded environment to that of full day vision. Specifically, throughout the thesis I shall refer to these NVG image conditions as a "visual degradation". "Visual degradation" will be used as a theoretical construct to assess spatial knowledge acquisition with and without NVGs.

To understand the possible influence of NVGs on spatial knowledge acquisition, this paper will review and examine the relevant spatial cognition, vision, and night vision enhancement devices literature. This literature review shall be used to understand how degraded visual information may impact the acquisition and use of spatial knowledge and the formation of "cognitive maps"

*Conceptual framework for understanding the acquisition of spatial knowledge through visual cues*

A hypothetical pathway of spatial cognition is presented. It is intended as a conceptual framework to better understand how people acquire spatial knowledge through visual cues during active navigation and wayfinding (see Figure 1).

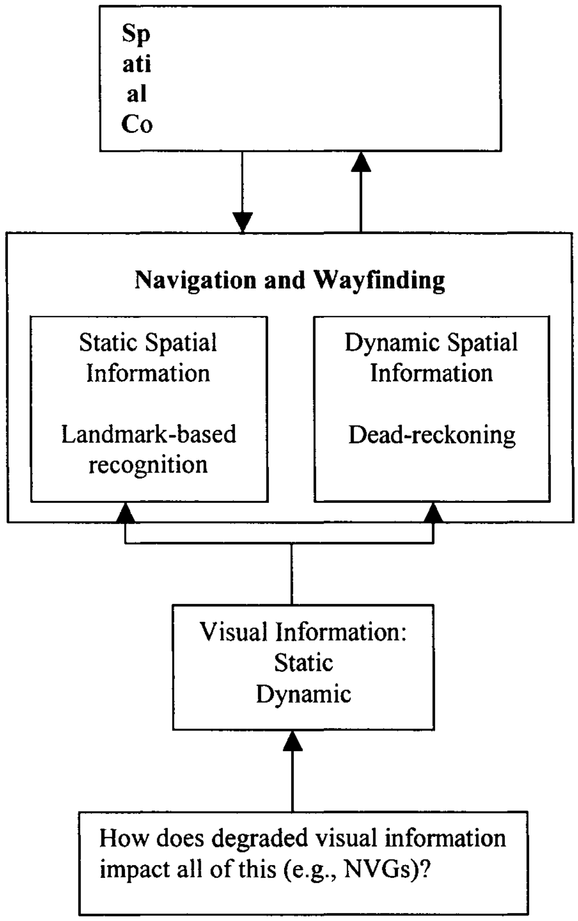



*Figure 1.* A hypothetical pathway of the impact of visual information on the acquisition of spatial knowledge.

The basic components of this framework are: the three types of spatial representations (i.e., landmark, route and survey knowledge); the tasks in which spatial cognition interacts with the environment (i.e., navigation and wayfinding); and the visual information involved in the acquisition and use of spatial knowledge (i.e., static and dynamic visual information). The three levels of this framework are related. Navigation and wayfinding leads to the acquisition of spatial knowledge. The type of visual information that is presented, meanwhile, can affect the acquisition and use of spatial knowledge through active navigation and wayfinding.

*What is spatial knowledge?*

Research on mental representations has shown that the three levels of knowledge representations, landmark, route and survey knowledge, are formed progressively (Siegel & White, 1975; Thorndyke & Hayes-Roth, 1982). First, feature-based representations of landmarks are used as spatial reference points that can be used to localize and orient while navigating. Landmark knowledge, therefore, is the visual representation of salient landmarks, or distinct features in the environment but are static, orientation dependent and disconnected from one another (Darken & Peterson, 2002). Second, a representation of route knowledge develops as landmarks are connected by paths (Hirtle & Kallman, 1988). Route knowledge is a sequentially organized series of procedures for how to get from one location in space to another (Darken & Peterson, 2002; Parush & Berman, 2004). Finally, survey knowledge or analog representation (Hinztman , O'Dell & Arndt, 1981) develops and contains information about the topographic properties of the environment (Thorndyke & Hayes-Roth, 1982; Wang & Spelke, 2002). It is an image-like representation of the entire geographical are that provides a "bird's eye view" of the environment. The different forms are spatial knowledge introduced are closely linked to the tasks that they enable a person to perform.

*How is spatial knowledge acquired?*

The formalization of spatial knowledge begins through active navigation within an environment. As people become more familiar with the environment, spatial knowledge is increased (Darken & Sibert, 1996; Thorndyke & Hayes-Roth, 1982). It has also been shown that the levels of spatial knowledge described above can be acquired simultaneously with the help of aids such as maps (Thorndyke & Hayes-Roth, 1982; Montello, 2003; McNamara, Timothy, Ratcliff & McKoon, 1984). For example, the use of maps can lead to survey knowledge without having to attain prior landmark or route knowledge, and eliminating the need for an exhaustive search of the area (Thorndyke & Hayes-Roth, 1982). However, it had been shown that knowledge acquired from direct experience leads to a more detailed mental representation that is not dependent on any point of view (Thorndyke & Hayes-Roth, 1982).

Taken together, the formation of mental representations involves landmark, route and survey knowledge that can be acquired from direct and indirect experience with the environment. Although landmark, route and survey knowledge may be learned simultaneously using maps, spatial knowledge acquired through direct environmental exposure leads to a more detailed, perspective-independent mental representation.

*The role of vision in the acquisition of spatial knowledge - Background*

It has been reliably shown that vision is the primary cue when experiencing the environment directly (e.g., Riecke, 2003; Rieser, Hill, Talor, Bradfield & Rosen, 1992). Indeed, empirical studies on navigation have shown that deriving navigation information from non-visual locomotion is difficult (Bigel & Ellard, 2000; Philbeck, Loomis &

Beall, 1997) and may influence the acquisition of spatial knowledge (Dodds, Howarth & Carter, 1982; Bigelow, 1996)

Evidence from studies with blind vs sighted participants suggests that acquiring survey knowledge may be influenced by prior visual experience (Dodds, et al., 1982; Jacobson, 1998; Bigelow, 1996). While spatial learning can occur in the absence of vision (Bigelow, 1996; Jacobson, 1998), the spatial knowledge typically remains at the level of route knowledge (Bigelow, 1996; Dodds et al, 1982). Indeed, studies with blind subjects have shown that although survey knowledge can be acquired in the absence of vision, it happens over more time and with more difficulty (Rieser et al., 1992; Bigelow, 1996). It has been argued that unlike other sensory modalities, vision is influential in the progression of spatial understanding from knowledge of routes travelled to overall layout knowledge of space. For instance, congenitally blind subjects and those who had suffered large-field losses early in life exhibited poorer knowledge of the spatial disposition of and relations between landmarks in their community than the other subject group (sighted, adventitiously blind, and those suffering early acuity loss but not large-field loss) (Rieser, et al., 1992). One obvious explanation is that sighted persons can observe the spatial relations among objects, (Bigelow, 1996; Cutting 1986; Nakayama & Loomis, 1974). Such empirical evidence suggests that while survey knowledge can be acquired in the absence of vision, vision appears to facilitate it, particularly when there is a large field of view.

The general question of this thesis is to what extent does vision play a critical role in the acquisition of spatial knowledge? Specifically, how do the visual implications of using NVGs (e.g. possible visual degradation) influence the acquisition of spatial mental representations through direct experience with the environment? The following sections will examine *the static and dynamic spatial and visual information* involved in navigation and orientation and in turn, how these cues may influence the development of spatial knowledge.

*Static spatial information (landmark-based recognition)*

Static visual cues include familiar retinal image size, texture gradient, accommodation, convergence, binocular disparity and FOV (Foley, 1980). Information from static visual cues gives information about the depth, size and distance of location cues. Static visual cues are the most precise channel for spatial and pattern recognition and are therefore the primary means used in humans to encode and recognize landmarks (Montello, in press).

Static visual cues are important for landmark-based recognition, also referred to as piloting, or view-dependent place recognition. Landmark-based recognition is a navigational strategy that involves orientation by recognizing landmarks to determine one's current position within the environment and also in terms of distance between oneself and the landmark (Wang & Spelke, 2002; Montello, in press: Diwadkar & McNamara, 1997; Sun et al., 2004). Likewise, when the destination is not visible from the current location, the recognized scene can indicate where the destination location is relative to the current position and designate a course of action. For example, in virtual studies of place-recognition navigation, it has been shown that people learn to turn in specific directions at particular places (Gillner & Mallot, 1998), and that their turning decisions depend on local, view-dependent representations of landmarks (Mallot & Gillner, 2000). Static visual cues, therefore, enable the detection and recognition of landmarks and the perception of the spatial layout of those landmarks within the immediate environment to maintain orientation and determine a course of action.

Studies on view-dependent representations and recognition of landmarks have also focused on the ability of humans and animals to remember a destination in terms of its distances to nearby landmarks or in terms of the relative directions in which those landmarks lie (bearing differences) (Waller, Loomis, Golledge, & Beall, 2000; Diwadkar & McNamara, 2004). For example, birds are able to find thousands of seed caches by using both distance and directional information of landmarks (Kamil & Jones, 2000). Recent studies have addressed the formation of distance information on place learning and landmark use in humans (Waller et al., 2000). These studies have shown that place learning in humans follow many of the principles of place learning in animals (Waller et al., 2000). An array of landmarks (static location cue) then, provides several distinct sources of information (i.e., distance and bearing information) that can aid a person in forming a mental representation of a place or objects (scene and landmark recognition) which can then be used to navigate and orient within the environment.

Finally, recent studies reveal that humans update static spatial representations (scene and landmarks) during locomotion (Wang & Spelke, 2000). Indeed, humans update these representations as they move in order to recognize the scene or localize an object from a different viewpoint effortlessly (e.g., Wang & Simons 1999). Moreover, humans' ability to recognize the scene can be impaired when disoriented between the study and the test (Simons & Wang, 1998). These findings suggest that humans update egocentric spatial representations during locomotion, and that updating is disrupted by disorientation. The next section will expand the review on the use of such dynamic, motion cues.

*Dynamic spatial information (dead-reckoning)*

In general, dynamic visual cues include optic flow (e.g., dynamic retinal information) for sensing self-motion (Warren & Hannon, 1990; Sun et al., 2004), as well as information about the motion of objects (Sun & Frost, 1998). Dynamic visual cues are important for dead reckoning, or path integration, a navigation strategy that involves keeping track of components of locomotion. Given the knowledge of the initial location, a person can update their orientation by keeping track of the velocity and/or acceleration (dynamic motion cues) as they move for a given period of time (Loomis et al., 1993; Sun et al., 2004; Klatzky, Loomis, Beall, Chance, & Golledge, 1998).

Dead reckoning is navigation that involves non-landmark representations such as optic flow (Loomis, et al., 1999). Moreover, under degraded visual conditions, dead reckoning may be a more heavily utilized navigational strategy that employs these dynamic locomotion cues (e.g., optic flow) (Riecke, von der Heyde & Bulthoff, 2002; Riecke, 2003). It was been suggested that dead reckoning provides a "glue" for the formation of mental representations (Loomis et al., 1999, Montello, in press). Dead reckoning and landmark-based recognition provide two sources of spatial information (e.g., static and dynamic) that may facilitate the formation of a mental representation of the environment (see Figure 1). Both of these navigational strategies may be disrupted by disorientation.

*Summary of static and dynamic spatial information involved in spatial cognition*

To summarize, how can the acquisition of mental representations through direct experience with the environment be influenced by static and dynamic visual information? Visual space perception is the ability to perceive the spatial layout of objects and surfaces within the immediate environment. It enables the detection and recognition of the direction and location of objects in relation to the viewer or to each other (Zalevski, Meehan & Hughes, 2001; Wang, & Spelke, 2002; Diwadkar & McNamara, 1997). It also permits the perception of egocentric (subject to target) and Euclidean (target to target) size and distance of objects using a variety of visual cues when stationary (static) and during locomotion (dynamic) (Waller et al., 2002; Wang & Spelke, 2000; Sun et al., 2004; Klatzky et al., 1998). These two types of spatial information allow for the formation and use of representations of the environment through which travel and the planning of effective routes in animals and in humans may take place (Loomis et al., 1993; Sun, Campos, Young & Chan, 2004; Wang & Spelke, 2000). Landmark-based recognition and dead reckoning are processes involved in human's perception of visual space.

*The impact of constrained viewing conditions on the acquisition and use of spatial knowledge*

Under normal viewing conditions humans are reasonable in judging the direction, distance and size of objects and navigating themselves around the environment. Errors in spatial judgment can occur under constrained or degraded visual conditions, for example when light levels fall, when viewing the environment through viewing devices such as NVGs, HMDs and thermal imaging systems (Zalevski et al., 2001; Hettinger, Nelson, &

Hass, 1996; Johnson, 2004) or naturally impaired human vision (Madden & Allen, 1995). Due to the optics of some viewings devices such as telescopes, binoculars, NVGs, the FOV is restricted relative to normal visual conditions. For example, the peripheral visual field is obscured (Geri et al., 2002) and has been hypothesized in leading to the compression of distance to targets on the floor (Durgin, Fox, Lewis, & Walley, 2002; Loomis & Knapp, 2003). Likewise, visual perception of depth and size of objects and Euclidean distance is reduced (Sheehy & Wilkinson, 1989; Niall et al., 1999; Reising and Martin, 1995). These factors can reduce the informational content of the visual scene which can affect the ability to encode and recognize landmarks and influence navigation and wayfinding.

Empirical evidence from recent studies suggests that degraded static visual cues can affect landmark and target acquisition and recognition (Barber, 1990; Aviram & Rotman, 1999; Seamon, et al., 1997; Wells & Venturino, 1990). For example, changes in image contrast (such as when viewing environment through NVGs and HMDs) can make recognition of objects and landmarks more difficult by reducing spatial information detail caused by a decrease in the local contrast among adjacent features of objects and landmarks (Geri, et. al., 2002; Niall, et al., 1999; Aviram & Rotman, 1999; Klymenko, Harding, Beasley, Martin & Rash, 1999). Likewise, it has been reported that performance in target detection decreases as image contrast decreases (Uttal & Gibb, 2001; Aviram & Rotman, 1999).

FOV has also been found to have an effect on spatial tasks such as visual search, walking and navigation tasks (Wells & Venturino, 1990; Ventrino & Wells, 1990; Cuqlock-Knopp & Whitaker, 1993; Arthur, 2000; Piantanida, Boman, Larimer, Gille, &

Reed, 1992; Riecke, Van Veen, & Bulthoff, 2002). Indeed, a wider FOV led to faster performance in a search and walking task (Arthur, 2000) as compared to a narrow FOV. A narrow FOV will reduce the number of landmarks available in the visual field demanding an increased need for head scanning (Geri, et al., 2002; Jennings & Craig, 2000). Furthermore, increased head scanning and reduced landmark recognition may increase spatial disorientation (Dolezal, 1982; Antunano & Mohler, 1992; Klymenko, et al., 1999). Taken together, degraded static visual cues such as visual acuity and FOV can reduce landmark and object recognition resulting in increased disorientation and low performance on visual spatial tasks.

In addition, it has been shown that degraded static cues can affect the perceived location and distance of landmarks in relation to the observer (egocentric view) or to each other (allocentric or exocentric view). For example, in the absence of distance cues such as visual depth cues (i.e., monocular viewing), observers typically underestimate the egocentric size and distance of landmarks (Halway & Boring, 1941; Reising & Martin, 1995). This compression of space increases with an increase of distance between viewers and objects or landmarks. Investigations of FOV in real and virtual environments have also found a compression of perceived distance (Dolezal, 1982; Kline & Witmer, 1996), although not all (Rowland, 1999; Creem-Regehr, in press). Researchers have reported that the world appears smaller to observers with restricted fields of view (Alfano & Michel, 1990; Dolezal, 1982). Therefore, reduced visual cues (e.g., FOV) can affect the perceived size and distance of landmarks which may compress perceived visual space.

It must be emphasized that egocentric estimates of distance to target may not be necessary for judgments about time-to-target (Delucia, 1999). Indeed, it has been noted that there is information in the optic array that specifies whether and when an observer reaches a target (e.g., Cutting, Vishton, & Braren, 1995), such as motion parallax or optic flow (see Rogers & Graham, 1979). Motion parallax, a distance cue during motion, refers to the appearance that closer objects move more rapidly in the optic flow field of a moving observer compared to the relatively slow angular velocities of more distant objects and terrain. Indeed, it has been found that when static visual cues are reduced or lacking, dynamic visual cues such as motion parallax are then used as the primary source of spatial information (Sun et al., 2004; Dijkerman, Milner, & Carey, 1996; 1999) however, the actual hierarchy of visual cues is still debated (Cutting, 1997; Mon-Williams, Tresilian, McIntosh & Milner, 2001). It has been found that optic flow alone is sufficient for estimating traversed distances relative to distances specified by a static landmark (Harris et al., 2000) under full-cue conditions. However, proprioceptive cues in conjunction with visual motion cues allow for the most accurate estimation (Klatzky et al., 1998; Sun et al., 2003), especially in reduced-cue conditions (Loomis et al, 1993). The conjunction of static and motion cues allow us to navigate well when particular cues are limited.

*Summary*

It has been shown in this review that static and dynamic visual cues are critical for efficient navigation and wayfinding. This is achieved by the person perceiving static and dynamic spatial information and by updating one's position within the environment while in motion (refer to Figure 1). Degradation in this visual information (e.g., a narrow FOV) can influence the perception and recognition of specific static and dynamic cues, increase disorientation and decrease performance on spatial tasks

*NVGs and the acquisition of spatial knowledge*

Over thousands of years of evolution humans have developed exceptional day vision, but have a somewhat less sensitive night vision system (see Johnson, 2004 for a review). To improve vision at night, humans have therefore opted for a technical solution by creating image intensification systems, or Night Vision Goggles (NVGs). While NVGs support and enhance visual perception in low-light or dark conditions, its use is different from visual perception in normal light conditions. It is widely accepted that the various physical characteristics (e.g. optical and electro-optical) of NVGs influence visual perception. For example, optical characteristics such as the limited (40°) field-of-view (see Jennings & Craig, 2000) contribute to a number of problems from an increased need for head movements to decreased perception of velocity and drift cues (Geri et al., 2002). The electro-optical components of NVGs that amplify available light create scintillating noise (i.e. a 'grainy' appearance similar to static noise on a television) within the visual display and may influence, depth (i.e., reduction in monocular and binocular cues), motion, size and distance perception (Uttal and Gibb, 2001; Vyrnwy-Jones, 2001; Sheehy & Wilkinson, 1989; Reising & Martin, 1995; Niall et al., 1999). While NVGs have been implicated in the spatial disorientation of pilots (see Braithwaite, Douglass, Durnford, & Lucas, 1998) the available data on how the physical characteristics of NVGs (e.g. optical and electro-optical) affect the acquisition of spatial knowledge is currently lacking.

While several laboratories have examined the effects of NVGs on visual perception, the data available on the effects of NVGs on spatial navigation is currently lacking and there are no data available in the public literature that evaluate the impact of

NVGs on the acquisition of spatial cognition (landmark, route, and in particular, survey knowledge) through active navigation and exploration.

Despite the paucity of such empirical investigations, evidence from research on NVGs (Vyrnwy-Jones, 1988; McLean, Rash, McEntire, Braithwaite, & Mora, 1997; McLean & Rash, 1999; Salazar, et al., 2003; Johnson, 2004) suggests that the degraded static and dynamic cues impact spatial perception and navigation performance. Furthermore, studies on perceptual learning suggest that spatial knowledge is affected by deficits in perception early in life (Rieser et al., 1992). Thus, it is reasonable to ask how and in what way degraded viewing conditions, such as through the use of NVGs, influence the acquisition of spatial knowledge.

## Study Proposal

The proposed study empirically examined the effects of NVGs on the acquisition of spatial knowledge through active navigation and exploration.

*Significance of an NVG Study*

The significance for studying the impact of NVGs on the acquisition and usage of spatial knowledge is both theoretical and practical. Theoretically, NVGs can provide a framework for investigating the influence of visual decrements on the acquisition and use of spatial knowledge. Devices such as these may allow an approach for studying how basic visual processes may contribute to spatial cognition.

While anecdotal reports suggest that Night Vision Goggles influence spatial navigation and wayfinding (Braithwaite at al., 1998), few studies have systematically characterized the nature of these effects. To address this issue, the current study examined the impact of NVGs on navigation and wayfinding performance and the acquisition of spatial knowledge. This research expands our understanding of the impact of NVGs on spatial cognition.

The current study provides a practical deliverable to military and paramilitary users for search and rescue and related operations. Indeed, NVGs have been particularly helpful in improving night operations in a number of domains (e.g. military, search and rescue, law enforcement). It is important to emphasize that NVGs significantly enhance our unaided night vision, and provide a safer operational environment for the user. However, they do not yet provide full normal day vision and NVG imagery delivers slightly difference visual scenery than these standard visual conditions. Findings from this investigation can be used to enhance NVG training programs and enhance development of the technology itself. In addition, these findings will be useful in the development of other HMD based systems where similar visual decrements are present (Darken et al., 1998; Rowland, 1999; Jennings & Craig, 2000; Edgar, Pope, & Craig, 1994).

*Research Approach*

The objective of this study is to examine the effects of visual degradation on the acquisition and use of spatial knowledge. Specifically, it was designed to examine how the use of NVGs, a form of visual degradation, can influence the acquisition of spatial cognition, survey knowledge in particular, through active navigation and exploration. The research approach will be based on a learning paradigm similar to Parush and Berman (2004). It will be composed of two main phases: a learning phase followed by some tests of survey knowledge. In the learning phase, users learn the environment through active navigation and exploration of a maze with (experimental group) or without (control group) NVGs. Three spatial tasks were administered in the testing phase, tests which reflect the impact of NVGs on the acquisition of survey knowledge.

*Methods for assessing survey knowledge*

There were two main dependent variables:

1. Navigation/wayfinding performance.
2. Orientation and the acquisition of survey knowledge.

Navigation and wayfinding performance is usually measured by objective criteria such as time to target, getting to the correct target, and deviations from the optimal route to the target (Edwards, Thompson & MacGregor, 1998; Holding & Holding, 1989; Goldin & Thorndyke, 1982). However, there has been a long-standing debate over how to measure survey knowledge. This problem probably starts with some difference of opinion as to exactly what constitutes survey knowledge. However, most agree that configuration knowledge is a well-documented network of locations (or landmarks) with multiple potential paths between them (Darken et al., 1998). The method with the greatest face validity to measure survey knowledge is map drawing. Typically, the experimenter asks the participants of the experiment to sketch rather hastily a map which represents a plan view of the place they previously explored (Dodds, et al., 1982; Bigelow, 1996). Maps sketches have been found to be a reliable method of data collection (Blades, 1990). Caution must be taken when interpreting results, however, as they are sensitive to methods of analysis, participants' spatial abilities and drawing ability (Darken et al., 1998; Henry, 2004).

More recent methods have centered on distance and bearing estimation tasks. Many distance estimation tasks express results in feet or as a ratio. In a study by McNamara (1986) for instance, participants were asked to verbally estimate the Euclidian distance in feet between objects. Allen and Willenborg (1998) have also used such a paradigm in their studies. It has been shown, however, that results of studies using such paradigm are subject to individual differences in spatial abilities (Holding & Holding, 1989; Radvansky, Carlson, Laura, & Irwin, 1995; Docherty, Van-Gyn, & Falkenber, 1986). The focus of this study, however, is with the subject's topological understanding of the environment (i.e., knowing where they are and where everything else is) as compared to metric knowledge (knowing precise object location and distance between objects). Rather than rely on metric knowledge, thus, it is intended to assess Euclidian (target to target) distance knowledge using an approach similar to Bigelow (1996). In a

Euclidian task, Bigelow (1996) asked children to imagine three magic ropes that go in a straight line through walls, ceilings, and floors and judge which magic rope was the shortest. A modified version of Bigelow's Euclidean task to test participants' judgement of Euclidian distance between objects was used.

Another technique to measure bearing or heading knowledge is called "point in the direction" technique (Klatzky, 1998). In this approach, participants are asked to point in the direction of a specific object or place they saw previously. It can either be done within the environment itself or from an imagined position within the environment (Rieser et al., 1992; Henry, 2004). Since the target objects are out of sight, participants have to extrapolate the location of the target using their cognitive map. The knowledge of direction using the pointer method from an imaged position within the environment was assessed as well.

The shortfall of the pointing technique and distance judgment tasks is that they contain less information than the sketch. It only measures peoples' estimates for the location of objects and spaces relative to each other and to the participants. Unlike the sketch, they do not show or represent relative sizes of spaces, or particular details and landmarks. There are advantages and disadvantages to both the sketch and the pointing and distance estimation methods. Although the pointing technique and distance judgment tasks are only a partial indication of people's cognitive maps, it is better suited for this study because it offers more specific quantifiable data. However, participants were also asked to draw a sketch. These results served to validate the pointing and distance judgment task results and explore unusual trends or findings.

*Research Questions*

The following research issues were defined to determine the effect of NVGs on the acquisition of spatial knowledge:

1. How do NVGs affect navigation and wayfinding performance?
2. Do NVGs influence spatial learning and the acquisition of survey knowledge?

*Main Hypotheses*

Because it was expected that NVGs influence spatial cognition (that is, wayfinding and the acquisition of survey knowledge), we formulated the following hypotheses:

1. *Acquisition.* Participants in the non-NVG (control) group will show a faster learning curve in terms of wayfinding performance compared to participants in the NVG (experimental) group.
2. *Survey knowledge.* Participants in the non-NVG group will show better performance in the orientations tasks (reflecting survey knowledge) such as relative pointing, the distance estimation and map drawing tasks as compared to the NVG group.

# Methods and Materials

*Participants*

52 men participated in the study. All participants were recruited from several related federal agencies (see Appendix A for Recruitment Statement). The age of participants ranged from 20 to 60 years. Participants had normal or corrected-to-normal vision. Participants were recruited on a voluntary basis. All participants had no prior experience using NVG. All experiments were in accordance with standard NRC Ottawa and Carleton's Psychology Research Ethics Board standard operating procedures. Dr. Todd Macuda currently has approval to conduct spatial navigation experiments with human participants at NRC.

*Study Design*

The experimental design was a between-participant design with participants randomly assigned to one of two conditions:

1. *NVG experimental group*: Participants were required to wear NVGs during a search and wayfinding task under normal lighting conditions.
2. *Non-NVGs control group:* Participants performed a search and wayfinding task under normal lighting conditions and without the use of NVGs.

*Experimental Tasks*

The following tasks were performed by all participants in the following sequence:

1. *Mental rotation test.* It is well known that individual spatial ability has a large effect on navigation ability, orientation responses and may affect distance judgments (Moffat, Hampson, & Hatzipanteli, 1998; Thorndyke & Hayes-Roth, 1982). Therefore, a test of spatial ability was conducted and used as a covariate in the

analysis. Participants were given a Mental Rotations Test, the MRT(A) to assess their spatial abilities (Peters, et al., 1995). The MRT(A) is a redrawn version of the Vandenberg and Kuse Mental Rotations Test (MRT) (Vandenberg & Kuse, 1978) which has been reliably shown to be an acceptable test of spatial ability (Shelton & Gabrieli, 2004; Voyer, Nolan & Voyer, 2000). The MRT-A by Vandenberg and Kuse (1995) was adapted from Shepard and Metzler's (1971) mental rotation test which has also been shown to be a valid and reliable test of spatial ability (Parsons, 1987; Sanders, Wilson & Vandenberg, 1982). The test was a paper and pencil test where each participant was given a 24-item set, and 3 minutes were given for each subset of 12 items, separated by 4 minutes (Peters, et al., 1995). The participant was required to fill in the forms. The version of the test can be found in Appendix B.

2. *Visual acuity test.* Since visual acuity can impact image clarity and spatial resolution (Oen, Lim, & Chung, 1994; Barber, 1990) and subsequently navigation and target acquisition (Madden & Allen, 1995; Kuyk, Elliott, & Fuhr, 1998), participants were selected with a baseline visual acuity of 20/25 using a standard Snellen test (Pinkus & Task, 2000). All participants met the baseline visual acuity.

3. *Learning phase: Search and wayfinding task.* Participants were required to search and locate various objects within the environment, with or without NVGs, according to their assigned condition. There were 12 navigation trials. Each trial was initiated at a random starting location and heading (every 30 degrees such as 0, 30, 60, 90, and so on). To ensure that navigation trials were compatible and similar in difficulty, the mean number of minimal navigation turns (3.5) and distance traveled (33 meters) were balanced across the 12 search tasks.

4. *Subjective Workload Assessment.* It has been suggested that when viewing the environment through viewing devices such as NVGs, greater attentional effort and resources may be required for navigational tasks, thereby increasing cognitive workload (Salazar, Temme, & Antonio, 2003; McLean & Rash, 1999). Therefore, a test to assess subjective workload was conducted. Following each navigation trial, the participant was asked the following question to assess their subjective workload: "Rate between 0 to 100 the extent of effort you needed to invest in order to perform the task (0=no effort, 100=extreme effort)".

The next three tasks were spatial memory tests to assess the acquisition and accuracy of survey knowledge. It is well documented that the knowledge of various topographical properties of an environment is indicative of survey knowledge (Thorndyke & Hayes-Roth, 1982; McNamara, 1986, Klatzky, 1998). These properties include knowing the location of objects in the environment relative to a fixed coordinate system (e.g., compass bearing), and the inter-object Euclidean (i.e., straight-line target to target) distances (Thorndyke & Hayes-Roth, 1982; Loomis et al., 1996, Bigelow, 1996). These tasks require participants to use their survey knowledge relatively free from their specific landmark or route knowledge.

5. *Judgement of Relative Direction (JRD) Task.* The relative pointing task required participants to indicate, from memory, where they thought an object is located within the maze, relative to an imagined position and heading. Since targets were out of sight, the assumption is that participants had to determine the direction of the target using their survey knowledge.

Participants were asked to point in the direction of a given object from an imagined position within the experimental environment (i.e. "Imagine you are standing at X and facing Y. Point to Z") (see Appendix C for instructions). The participant was then required to record his decision on a circle with a dot in the center of each to record his decision. This direction recording has been adapted from Magliano, Cohen, Allen and Rodrigue (1995). Participants were instructed to draw a line from the dot to the edge of the circle to indicate the direction of the objects they were asked to point to. Participants were told that the top of the circle in which they recorded their direction decision, indicated with an X, was always considered oriented in the direction they are facing (see Figure 2).

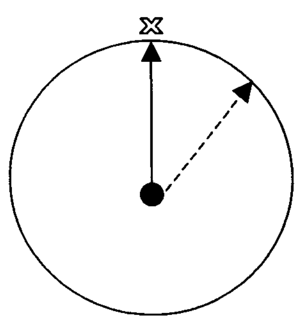



*Figure 2.* Example of the circle used in the JRD task in which participants recorded their direction decision. The dotted arrow symbolizes the correct direction of the object.

There were a total of 24 randomly assigned orientation tasks (see Appendix D for the list of questions). This number of orientation tasks is in accordance with similar studies on the assessment of topographical knowledge (Parush & Berman, 2004).

Questions were setup according to: (1) *type of object:* whether it was a target, one of 12 objects that were searched in the search task, or distracters, objects that were not targets; and (2) *location proximity:* whether the objects in the question were located within the same room or in separate rooms. The type of test was chosen to assess the acquisition of explicit (knowledge of objects and their location previously searched for in the search task) and implicit (knowledge of objects and their location not searched for but encountered in the search task, referred to as distracter objects in the visual search literature) survey knowledge. The location of the objects determined the difficulty level of the task. For example, a relative pointing task involving two objects located in the same room was expected be an easier task to resolve than a task involving two objects located in separate rooms. It was assumed that participants would have to determine the location of the target using their survey knowledge in the absence of barriers between the two objects – "theoretically" making the task easier to resolve. As a result, the task was comprised of 6 categories of questions (see Table 1).

*Table 1.* The 6 categories of questions in the JRD task according to type of object and object location proximity.

| Within Same Room | | | In Separate Rooms | | |
|---|---|---|---|---|---|
| Search | Not Searched | Mixed | Searched | Not Searched | Mixed |

6. *Distance Judgment Task.* Participants were asked to determine, from memory, which one of three objects within the experimental environment was closest, in a straight-line distance, to a specified object (see Appendix E for instructions). The task was adopted from the study by Bigelow (1996). There were three distances to choose

from and all distances started from one position (target object) and went to one of three objects (see Figure 3 for a visual example).

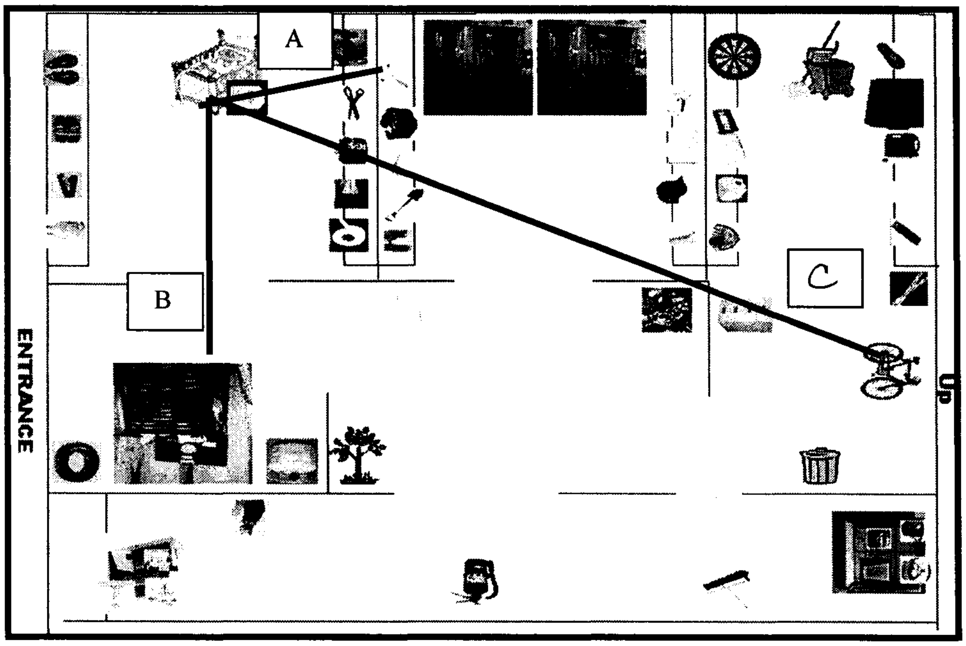



*Figure 3.* A visual example of a distance judgment. One location, (A), was closest in straight-line distance to the test object (Crib), one location was clearly closest by route (B), and one location that was neither closest by route nor in a straight-line distance (C).

All objects referred to in the task were objects in the experimental environment. An example would be:

> "Test object: Crib
>
> a. Paint roller handle
>
> b. Toolchest
>
> c. Bicycle"

One location was clearly closest in straight-line distance to the test object but not nearest by the actual route necessary to take to that location from the test object (A). In a similar manner, one location was clearly closest by the route necessary to take to the location from the test object but not closest in straight-line distance to the test object (B). The third location was chosen as an arbitrary location that was neither closest by route or in a straight-line distance (C). There were 3 categories of questions for this task: targeted objects, distracters and mixed. There were 24 randomly assigned tasks to complete. See Appendix F for the list of questions.

5. *Map Drawing.* This task required the participant to draw a map, from memory, of the environment they learned in the learning phase. They were simply instructed to draw everything they could remember, and to label all objects and features rather than draw them. The participant was given 5 minutes to perform this task. This approach allowed measuring participants' ability to re-construct space, including the size of all the individual spaces, their location relative to each other as well as particular details and landmarks. Due to the subjective nature of sketched maps, the data acquired in this study were used as a qualitative assessment of the participant's cognitive map. It must be underscored however, that sketch techniques are difficult to analyze and are sensitive to people's drawing ability (Henry, 2004). For these reasons, the sketched maps were used for qualitative representation of the participant's cognitive map.

*Measurements*

Performance measurements were recorded and collected for all trials and conditions. The performance measurements included the following:

*Navigation performance measurements.*

1. *Navigation duration.* From the time the blindfold was taken off or NVGs turned on until the participant shouted "object found", indicating the end of the trial.

2. *Number of navigational turns.* The actual number of navigational turns the participant took to locate the object from the starting location. A navigational turn refers to a full body rotation towards a different heading, not a head scanning.
3. *Number of unnecessary turns (relative to optimal route).* The difference between the route taken by the participant and the route required to perform task optimally. An optimal route refers to the minimum number of turns the participant needed to take to locate object from starting location. The deviation was the actual number of turns taken from the optimal route.

*Relative Pointing Measurements.*

1. *Orientation deviation.* The deviation, in degrees, between the correct directions of the test object and the actual recording direction of the participant. The deviation was recorded by calculating the absolute difference between the line pointing to the correct direction of each test object location and the line the participants drew. The absolute deviations in degrees ranged between 0° and 180°. The means of these deviations were submitted for analysis. Figure 4 illustrates this measurement.

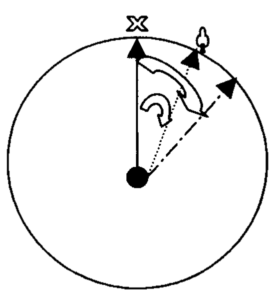


*Figure 4.* A visual example of the orientation deviation measurement. The deviation was recorded by calculating the absolute difference between the line pointing to the correct direction of each test object location (the arrow pointing to the object icon) and the line the participants drew (the broken arrow).

2. *Unanswered questions:* Number of unanswered questions in the relative pointing task.

*Distance Judgment Measurements.*

1. *Distance judgement correctness.* The correct response for judging target-to-target distance. The mean number of correct responses was submitted for analysis.

*Map Analysis Measurements.*

1. *Correct object placement.* The ratio between number of correctly placed objects drawn on the map and the total number of objects drawn on the map.
2. *Number of rooms drawn.* Number of rooms drawn on the map.
3. *Map goodness scores.* A simple technique, map goodness, was used to analyze the drawn maps. This technique has been adapted from Billinghurst and Weghorst (2004). Maps were ranked for goodness on a scale of 1-5 by three judges who were familiar with the experimental environment but blind to the participant's identity and group affiliation. The raters/judges were be told to rank the maps on how useful they would be as a navigational tool if they were taken with them into the maze. They were told to ignore the participant's drawing ability and focus on how well the map represents the experimental environment and the locations of the objects within it.

*Materials and Apparatus*

*Experimental setup.* The experimental setup involved three main areas located in a storage facility at NRC's Flight Research Lab (see Appendix G for building layout). The final building layout was determined through pilot testing.

1. *Testing Area.* This area was setup with a desk and laptop where the participant filled out all questionnaires (consent forms, introduction questionnaire, MRT-A), and

performed the three spatial memory tasks (JRD, distance judgment, and map drawing). This area was away and closed off from the navigation environment.

2. *Equipment Fitting/Vision Testing Area.* The purpose of this area was to perform the visual acuity tests and for the NVG mechanical and focusing adjustments and familiarity session. This area included a table (with chin rest and NVG-mount), focusing stimulus (Snellon chart and USAF Tribar chart test), and an open area for the familiarization session with NVGs. See Appendix H for the chin-rest and NVG-mount setup.
3. *Experimental navigation environment.* The environment was a 36 x 28 foot area constructed from wood frame wire-mesh dividers covered with a fire resistance black material (see Appendix I).

*Landmark and object configuration.* Prominent, highly visual and salient landmarks (i.e., garbage can, broom, plant) were placed at various locations in the experimental navigation environment. In addition to the landmarks, objects were placed at various locations within the environment. Since landmarks and grouping of objects serve to support navigation and possibly the development of survey knowledge, the choice of landmarks and object groupings and their layout is crucial (Vinson, 1999). Although originally proposed for virtual worlds, some of Vinson's (1999) guidelines for the choice and layout of landmarks and objects were used in this study. For instance, objects were grouped together in such a way that each room in the environment had some "fuzzy" themes. Some of these landmarks and objects served as the search targets in the navigation task. Figure 5 illustrates the layout of the environment, including landmark and object location, and the fuzzy theme associated with each room.

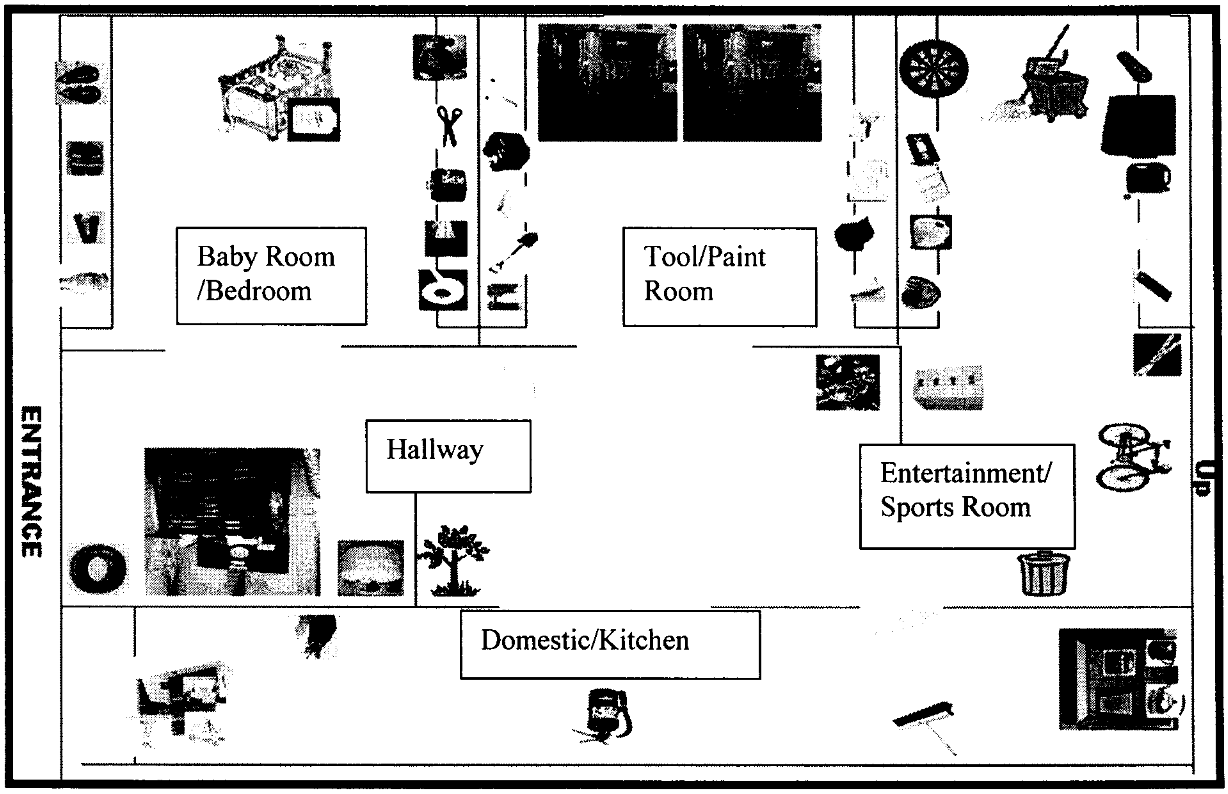



*Figure 5.* Layout of experimental environment, including landmark and object location and the fuzzy theme associated with each room.

*Night Vision Goggles.* Participants in the experimental group were fitted with a pair of ANVIS (Aviator Night Vision Imaging System) 9, F4949 set of Night Vision Goggles (NVGs) during the navigation task. Appendix J depicts a standard Anvis system.

To ensure that all light independent of the NVG displayed imagery was eliminated the NVG goggles were shrouded on the sides with a specially devised set of ski goggles and mask. The ski goggles were setup with a hard black plastic and 2 holes big enough to accommodate the eyepiece of the NVGs. The mask was made from a black, non see-through material, placed over the participants' helmet mount and fixed to the goggles. With the specially devised ski goggles and mask, the peripheral vision was completely blocked. Corrective lenses were worn behind the ski goggles and mask. This design was a result of extensive pilot testing. See Appendix K for an illustration of this head-mount setup.

*NVGs and optical pinholes.* The optics of the standard Anvis-9 are set to provide a focused optical system at infinity. This means that the system was focused to beyond 20 feet from the observer so that items closer to the observer would be unfocused without some minor modifications to the system. To achieve this modification, a pinhole (literally a hole the size of a pin) was placed in front of the NVG lenses. This artificially modifies the focal length of the lens and allows a well focused stimulus to be perceived at distances close to the observer (e.g. 6 inches to 20 feet). Inserting an aperture or pinhole in front of the lens increases the depth of field or zone of sharp focus for an image and in this case enhances the range of nominal focused resolution for the observer (Young, 1989). In addition, adding a pinhole to the NVGs allows navigation tests to be conducted in full light conditions. This also ensured that participants experienced the same nominal light level for all tests and comparisons.

The level of light experienced in the NVG imagery, and thereby imagery displayed to the user (i.e., resolution, scintillating noise, monochrome vision) with pinholes, is consistent with a level of half moon light conditions without pinholes (RCA Electro-Optic Handbook, 1974). The resulting FOV was nominally set to 30 degrees.

*Adjustment and focusing procedures for NVGs.* It is important to properly focus the NVGs to ensure that clear imagery is displayed to the participant. Well-focused stimuli will prevent eye fatigue associated with accommodative and other compensatory visual mechanisms subsequently preventing headaches or fatigue to the participant. In addition, well-focused imagery will minimize a negative impact on wayfinding that could be attributed to poorly focused goggles.

Participant adjusted their goggles then focused them to ensure clear imagery. First, participants had to ensure that interpupillary distance (distance between the eyes) was set correctly for their eyes and that a single fused image was available. Next, participants focused the goggles to ensure clear imagery. The system provided nominal behavioural acuity in the 20/25-20/40 range depending on individual and relative focusing procedures. Participants were focused nominally to a 20/40 level which is consistent with a level of half moon light conditions without pinholes. To obtain a visual acuity of 20/40, participants focused the goggles using an objective (course adjustment) lens and eyepiece lens (fine focus) of the NVG tubes. NVG focal adjustment requires a user to focus one at a time the objective lens of the NVG tubes. To this end, one eye has to be closed or one of the tubes has to be covered during NVG focal adjustment. The NVG image is then fine-tuned further by rotating the diopter ring counter-clockwise towards the positive (starting from zero diopter). The counter-clockwise rotation of diopter ring is then stopped and paused for a second when the image just becomes blur. The diopter ring is then rotated slowly clockwise, until the image just becomes sharp (Task, 1997).

Participants were presented a focusing stimulus (USAF Tribar chart test) and instructed to focus the objective lens and then the eyepiece to establish a clear image of a range of bars. The USAF test involves an observer viewing these stimuli and stating the group and element he could resolve (see Appendix L). Two easily detectible gratings (20-60 and 20-80) were then presented to ensure that sharp focus was present for the grating stimuli (see Appendix L). An experimenter was present to assist the participants with the NVG adjustments.

*Military helmets.* NVGs were mounted onto a Canadian issued military helmet and secured with a NVG head-mount. To ensure that the helmet was not a factor in the navigation and wayfinding performance, participants from the control group were also required to wear a helmet during the search and wayfinding task.

*Technical set-up.* Normal indoor lighting was used in both the control and experimental condition. As mentioned above, this provided an illumination level in the NVG displayed imagery of half to full moon natural conditions.

Participants' positional movement during the navigation and wayfinding task (e.g. time to target, navigational route and number of turns within route) were recorded on paper by the experimenter.

The JRD and distance judgment tasks were administered on a Panasonic Toughbook laptop (Model No. CF-18) in the testing area. E-Prime version 1.1, a psychological software tool comprised of a suite of applications, was used to administer the questions related to each task in a random fashion and to collect participants' responses. E-Studio was used to create the JRD and distance judgment tasks and E-Run was then used to run the stimulus presentation (questions related to the task) and for data collection. See Appendix C a task flow for the JRD and Appendix E for a task flow for the distance estimation tasks.

*Procedure*

Participants were briefed according to standard NRC and Carleton's Psychology Research Ethics Board operating procedures. They were then required to complete an informed consent form with a general description of the experiment and its requirements (See Appendix M). Participants were randomly assigned to one of the two experimental conditions.

Participants were tested individually. First, they performed the MRT-A to assess their spatial abilities. Following the MRT-A, participants' visual acuity was measured using Snellen acuity test (see Appendix N for standard Snellen eye chart).

Participants in the experimental group were then fully briefed on adjustment and focusing procedures in an interactive session with the experimenter. At the beginning of testing participants spent approximately 10-15 minutes first adjusting their goggles then focusing them to ensure clear imagery. Participants' visual acuity was nominal set to 20/40 in an iterative process whereby they adjusted and focused their goggles until the desired nominal acuity was achieved. The adjustment and focusing procedure was followed with some training on the use and handling of NVGs. Participants were given 5 minutes to walk around with the NVGs to become familiar with the visual distortions due to NVGs. The entire adjustment and handling procedures with NVGs lasted 20-25 minutes.

The testing procedures employed presented no risks to the participants. The Flight Research Laboratory (FRL) at the NRC has a well established protocol for testing NVGs with human participants. The procedures used in this study are well-established safe and effective non-invasive methodologies for assessing the influence of NVGs on locomotion and wayfinding performance.

There was a minimal risk of increased head loading due to the weight of NVGs during the navigation task. While it has been found that neck muscle fatigue can occur during head loading, it only develops after prolonged use of NVGs (Thuresson, Ang, Linder & Harms-Ringdahl, 2003). Since the navigation tasks were setup to allow breaks between search tasks, neck muscle fatigue was minimized. On average, breaks in wearing NVGs were given every 10-15 minutes. Participants were instructed that they could quit anytime during the session. To ensure safe locomotion and wayfinding during the navigation task, an experimenter always accompanied the participant.

At the beginning of the navigation and wayfinding task, participants in both the control and experimental group were fully briefed on the specific description of the navigation task and its requirements. In particular, they were instructed to find the target as quickly and as efficiently as possible (see Appendix O). Following the debriefing, participants were led into the experimental environment to a specific starting location and heading to begin the first trial of the search and wayfinding task. At the beginning of the trial, participants in the control group were blindfolded while participants in the experimental group had the NVGs turned off. While still blinded, participants were given the instruction to locate a given target within the environment. Participants were instructed to repeat the name of the target and its description to ensure proper identification of the target. Then, either the blindfold was removed, or the NVGs were turned on and the participant began looking for the target when the experimenter said "Begin". Once the participant had located the target, they were required to face the target perpendicularly, point to it, and announce, "Object found". The experimenter then confirmed that the correct object was found. Finally, the participant was required to answer a workload assessment question. At the end of the trial, the blindfold was again placed over the eyes for the control group, or the NVGs turned off for the experimental group, and the participant was then taken to a new starting location, facing another 30 degree heading and given the next task and so on. This order was randomized across both conditions.

Once the navigation trials were completed, the participants were relocated back to the testing area. Participants were randomly assigned to one of three spatial memory tasks to assess the level of survey knowledge. The three tasks were given in a random order. The participants were debriefed following the completion of all tasks. (See Appendix P for debriefing form).

# Results

*Learning Phase: Search and wayfinding*

It was hypothesized that NVGs would impact: (1) wayfinding and navigation performance; and (2) variation of this performance as a function of the practice block. To analyze the performance of search and wayfinding with and without NVGs, the 12 search trials were divided into 4 blocks, each consisting of 3 trials. The analyses of the actual time to target, number of navigation turns and navigation errors were performed on the means of each block. Prior to all analyses, data was checked for outliers, missing data, and normality to verify that there were no violations in statistical assumptions.

Because it was expected that NVGs would influence spatial cognition (that is, wayfinding and the variation of this performance as a function of the practice blocks), multiple pairwise comparisons were performed to investigate for block effects and the specific shape of the learning curve for each of the two groups.

It is well known that individual spatial ability has an effect on navigation and wayfinding, and spatial task performance (e.g., Moffat, et al., 1998; Thorndyke & Hayes-Roth, 1982; Voyer, Nolan, & Voyer, 2000). In order to examine whether individual spatial abilities had any confounding impact on performance in this study, Mental Rotation Test (MRT) was used as a covariate in various analyses. The MRT score was calculated by giving one point per question if the participant matched both of the stimulus figures to the target figure correctly. No credit was given for a single correct answer, for a maximum score of 24. Each analysis included a prior test to determine if MRT was an appropriate covariate.

*Time to target.* The Levene's test for equality of variances revealed that there was a violation on the assumption of homogeneity of variances on the mean navigation time. A log transformation (base-10 logarithm) of the mean navigation time of the blocks was performed. A Levene's test for normality on the transformed data confirmed homogeneity of variance.

MRT was found as an appropriate covariate to this analysis along with a log transformation of the time data (the details of the analysis are outlined in Appendix R). In order to analyze the performance of mean time to target with and without NVGs, a 2 (NVG vs Control) by (4) (Block) with MRT as the covariate ANCOVA with repeated measures in the block factor was performed on the transformed data. The analysis revealed a main effect attributable to group assignment, $F(1,49) = 60.817$, $p<.001$ (see Figure 6).

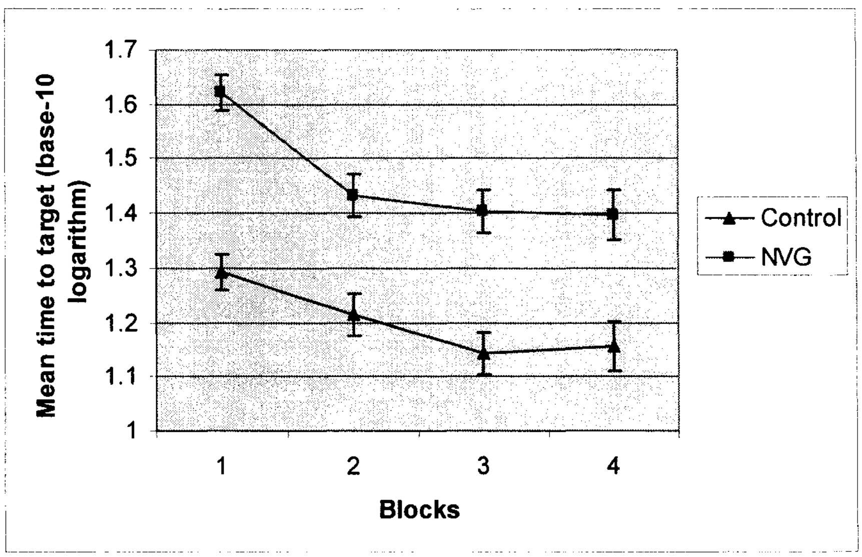



*Figure 6.* Mean time to target (+*SE*) for the NVG group and the control group as a function of blocks in the search and wayfinding task.

It can be seen in Figure 2 that mean navigation times across all blocks while wearing NVGs were longer as compared to not wearing NVGs. It can also be seen that mean navigation times for both the control group and the experimental group decreased as a function of the blocks. However, the decrease in mean navigation times while wearing NVGS as compared to not wearing NVGs varied as a function of the blocks. To investigate this further, multiple pairwise comparisons with Bonferroni correction were performed. It was revealed that mean navigation times for the NVG group were significantly shorter in the second ($M = 1.434$, $SE = .039$) third ($M = 1.404$, $SE = .039$) and fourth ($M = 1.397$, $SE = .045$) block as compared to the first block ($M = 1.623$, $SE = .032$, $p<.05$). There was only a significant difference in mean navigation times between the third ($M = 1.143$, $SE = .039$) and first block ($M = 1.294$, $SE = .032$, $p<.05$) for the control group.

In summary, search and wayfinding performance in terms of time to target was longer when using NVG as compared to the control group. However, there was a significant decrease in mean navigation time earlier (in the second block) while wearing NVGs compared to not wearing NVGs (significant decrease only at the third block). In addition, mean navigation time continued to decrease significantly across all blocks compared to the first block when wearing NVGs.

*Number of navigation turns.* MRT was not a significant covariate ($F<1$) and was thus excluded from the analysis. In order to analyze the performance of mean number of navigation turns with NVGs, a 2 (NVG vs Control) x (4) (Block) ANOVA with repeated measures in the block factor was performed. The analysis revealed a main effect attributable to group assignment, F(1,50) = 20.453, p<.001, and a main effect of block, F(3,150) = 3.640, p<.05 (see Figure 7).

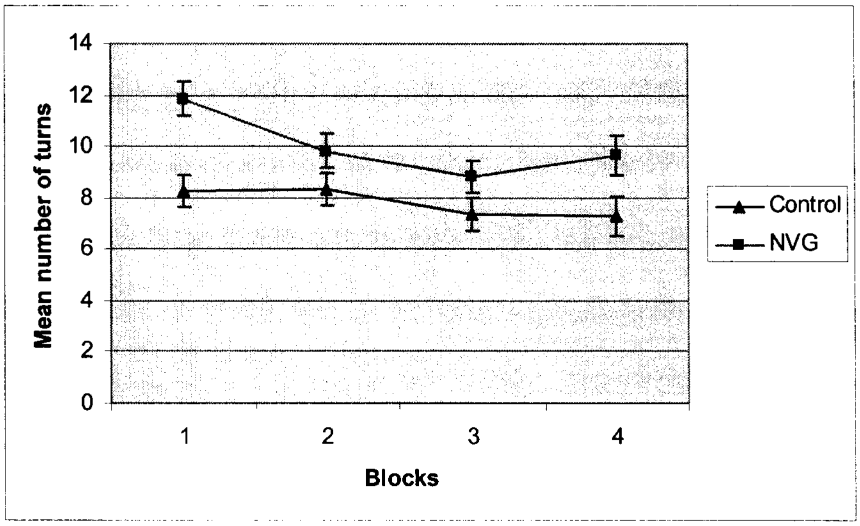



*Figure 7.* Mean navigation turns (+*SE*) for the NVG group and the control group as a function of the blocks in the search and wayfinding task.

A trend analysis was used to analyze the decrease of the mean number of turns over the four blocks as a function of group assignment. Significant linear, F(1,25) = 4.967, p < .05, and quadratic, F(1,25) = 5.069, p < .05, trends were detected for the experimental group. For the control group however, only a linear trend approaching significance, F(1,25) = 4.093, p=.054, was found. To further investigate this trend, multiple pairwise comparisons with Bonferroni correction were performed. For the experimental group, mean navigation turns were significantly lower in the third block (*M = 9.146, SE = .655, p<.05*) compared to the first block (*M = 11.946, SE = .639*). No significant differences between blocks were found for the control group.

In summary, the results indicate that while mean navigation turns generally decreased over the four blocks for both groups, this trend varied as a function of group assignment. While wearing NVGs, mean navigation turns decreased significantly in the third block, with an increase in the fourth block. While not wearing NVG there were no significant increases or decreases in turns across the blocks.

*Number of unessential navigation turns.* MRT was not a significant covariate (F<1) and was thus excluded from the analysis. In order to analyze the performance of mean number of navigation errors with NVGs, a 2 (NVG vs Control) x (4) (Block) ANOVA with repeated measures in the block factor was performed. This analysis revealed a main effect attributable to group assignment, $F(1,50) = 20.969$, $p<.001$, and a main effect of block, $F(3,150) = 4.016$, $p<.05$ (see Figure 8). It can be seen in Figure 8 that the mean number of unessential turns for both groups generally decreased over the four blocks. It can also be seen that the mean number of unessential turns while wearing NVGs was significantly higher as compared to not wearing NVGs.

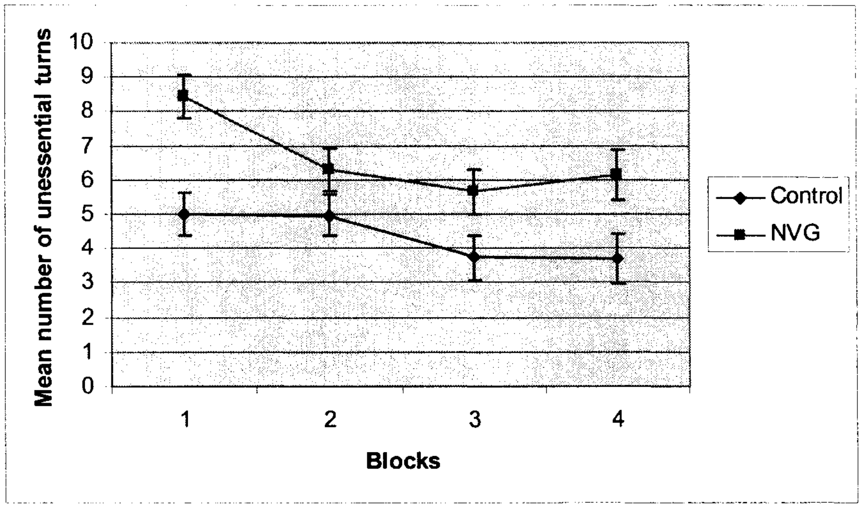



*Figure 8.* Mean navigation errors (+*SE*) for the NVG group and the control group as a function of the blocks in the search and wayfinding task.

A trend analysis was used to analyse the decrease of the mean number of unessential turns over the four blocks as a function of group assignment. Significant linear, $F(1,25) = 5.210$, $p < .05$, and quadratic, $F(1,25) = 4.636$, $p < .05$, trends were detected for the experimental group. For the control group however, only a significant linear trend was found, $F(1,25) = 7.127$, $p < .05$. To further investigate this trend, multiple pairwise comparisons with Bonferroni correction were performed. For the experimental group, the mean number of unessential turns was significant higher in the first block (*M = 8.435, SE* = .633) compared to the third block (*M = 5.662, SE = .655, p*< .05). No significant differences between blocks were found for the control group.

In summary, the results indicate that while the mean number of unessential navigation turns generally decreased over the four blocks for both groups, this trend varied as a function of group assignment. While wearing NVGs, the mean number of unessential turns decreased significantly in the third block, with an increase in the fourth block. While not wearing NVG there were no significant increases or decreases in unessential turns across the blocks.

*Subjective workload.* MRT was not a significant covariate ($F<1$) and was thus excluded from the analysis. One participant was not included in the analyses as his workload scores were lost. In order to analyze subjective workload with NVGs as a function of blocks, a 2 (NVG vs Control) x (4) (Block) ANOVA with repeated measures in the block factor was performed. A significant main effect of block was found, $F(3, 147) = 5.238$, $p<.005$. Figure 9 shows that the pattern of subjective scores followed a similar pattern as the patterns found in the number of navigation turns and unnecessary turns.

To investigate this further, a trend analysis was performed. Significant quadratic, $F(1,25) = 8.786$., $p < .05$, trends were detected for the experimental group. In other words, there was a decrease in the second block compared to the first block, but then the

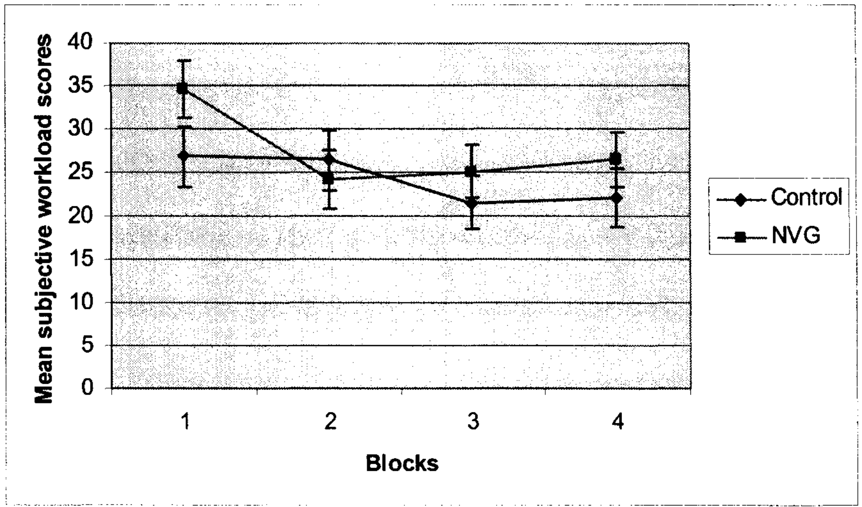



*Figure 9.* Mean subjective workload scores (+*SE*) for the NVG group and the control group as a function of blocks in the search and wayfinding task.

scores began to increase in the third and fourth blocks. For the control group however, only a significant linear trend was found, F(1,24) = 4.245, p =.05. In other words, the scores decreased steadily over the four blocks. Multiple pairwise comparisons with Bonferroni correction were performed to investigate the trends as a function of group assignment. The results revealed that for the experimental group, subjective workload scores were significantly lower in the second (*M = 24.115, SE = 3.307*), and third (*M = 25.039, 3.036*), compared to the first block (*M = 34.651, SE = 3.358,* p<.05) . No significant differences between blocks were found for the control group.

In summary, the results indicate that while wearing NVGs in the navigation phase, there was a significant decrease in the subjective workload scores in the second block but then scores steadily rose over the third and fourth block but did not get as high as in the first block. While not wearing NVGs, subjective workload decreased steadily over the blocks without any significant increases or decreases between blocks.

*Summary of learning phase: Search and wayfinding results.* The results show that participants generally became quicker, more accurate and found that less effort was required in carrying out the search and wayfinding task over the course of the blocks. These results are to be expected because participants gained more experience of the environment and with the task during the 12 search and wayfinding trials. Change in performance over the blocks, however, varied as a function of group assignment, indicating that NVGs influenced the learning process. The results of the learning phase therefore support the hypothesis that NVGs would impact wayfinding performance and variation of this performance as a function of learning block

*Testing Phase: Testing survey knowledge*

It was hypothesized that participants in the control group would show better performance in the orientations tasks (reflecting survey knowledge) such as relative pointing, the distance estimation, and the map drawing tasks, as compared to the NVG group. To test this hypothesis, several separate analyses on each of the tasks were performed.

*Relative pointing test: Orientation deviations.* In order to analyze the performance of the JRD tasks with and without NVGs, the scores were divided according to: (1) three types of objects addressed in the question (search targets, distracters, mix of targets and distracters); and (2) whether both objects were located in the same room or in two separate rooms. This resulted in 6 categories (3 types X 2 location proximities). The analyses were performed on the mean orientation deviation for each category.

Some questions, out of the 24 questions for relative pointing task, were left unanswered. However, since the analyses were performed on the mean orientation deviation of each category, missing data was substituted by taking the average deviations of answered questions for each category for a given participant. Two participants were not included in the analyses due computer failure and their scores were lost. Two other participants were identified with the Grubb's test for outliers (Grubb's, 1969) and were removed from that data set.

MRT was found as an appropriate covariate in this analysis (see details in Appendix N). In order to analyze the performance on the orientation task with NVGs, a 2 (NVG vs Control) x 2 (objects located in the same room or in two separate rooms) x (3) (targeted, distracters, mix of targeted and distracters) ANCOVA with MRT as the covariate was performed. A significant group x location proximity x object type interaction was found, $F(2,86) = 5.569$, $p < .005$. This interaction is presented in Figure 10.

As can be seen from the graph, mean orientation deviations for both groups were significantly lower (i.e., better performance) when questions referred to two target objects compared to two distracter objects or a mix of both. However, mean orientation deviations between the NVG group and the control group depended on the type of objects referred to in the task and whether those objects were located in the same room or in separate rooms.

Multiple comparisons with Bonferroni correction revealed the following:

1. *Two target objects located in the same room:* no significant differences between groups.

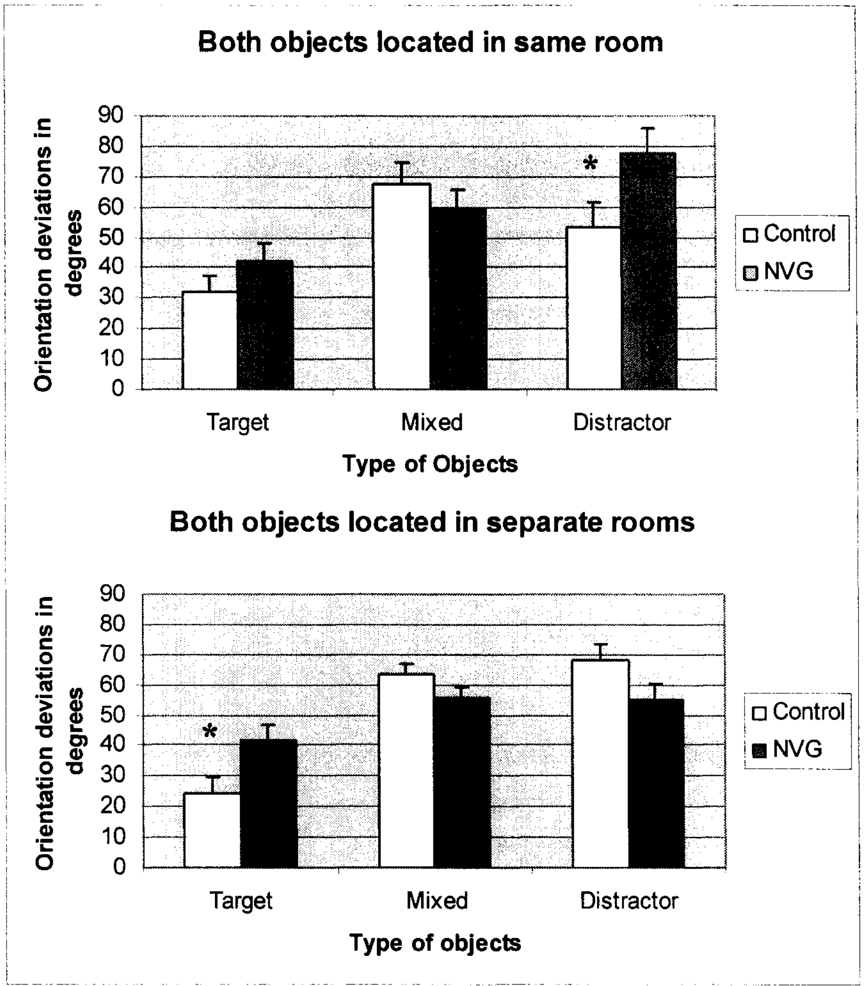



*Figure 10.* Mean orientation deviations (+*SE*) for the NVG group and the control group according to the type of object (targets, distracters and mixed) located within the same room (top panel) and in separate rooms (bottom panel). Note: * depicts significantly lower deviation scores in the control group (p < .05) compared to the NVG group.

2. *Two target objects located in separate rooms:* the control group had significantly lower deviations scores (*M = 24.374, SE = 5.342*) compared to the experimental group (*M = 41.441, SE = 5.342, p<.05*).

3. *Two distracter objects located in the same room:* the control group had significantly lower deviations scores (*M = 53.050, SE = 8.291*) compared to the experimental group (*M = 77.820, SE =8.291, p<.05*).

4. *Two distracter objects located in separate rooms:* no significant differences between groups.
5. *A mix of targets and distracter objects located in the same room:* no significant differences between groups.
6. *A mix of targets and distracter objects located in separate rooms:* no significant differences between groups.

In summary, the control group had significantly lower orientation deviation scores (i.e., better performance) compared to the experimental group when the questions in the JRD task referred to two targeted objects located in separate rooms and to two distracter objects located in the same room. There was no significant difference between groups for mixed objects. These results suggest that compared to not wearing NVGs, wearing NVGs in the learning phase significantly impacted the acquisition of orientation accuracy and the degree of acquired explicit (target objects) and implicit (distracters) survey knowledge.

*Relative pointing task: unanswered questions.* Missing data was investigated to see if there were any significant differences in the proportion of unanswered questions between the experimental and control group. Unanswered questions may have reflected participants' inability to answer the question due to lack of knowledge about either the orientation of the object, or of the object itself. This was confirmed by question marks left beside unanswered questions, or comments made following the task.

The proportion of unanswered questions in the experimental group was .16 whereas the proportion in the control group was .10. The difference in proportions approaches significance, $\chi^2$ (1, n=48) = 2.885, p = .089. The largest difference in the proportion of answered questions between groups occurred when questions involved 2 distracter objects. The proportion of unanswered questions in the experimental group was .32 whereas the proportion in the control group was .14. The difference in proportions was significant, $\chi^2(1, n = 48) = 4.574$ $p = .032$. Therefore, participants in the NVG group were more likely to leave questions unanswered in the JRD task, particularly when both objects were distracters, compared to the control group. This data would suggest that the experimental group had acquired less implicit knowledge during the learning phase than the control group.

*Distance estimation.* In order to analyze the performance of distance estimation tasks with NVGs, the scores were divided according to the type of object (search targets, distracters, mix of targets and distracters) addressed in the question. The analyses were performed on the mean number of correct responses of each category. One participant was excluded from the analysis due to computer failure.

MRT was not a significant covariate ($F<1$), and was thus excluded from the analysis. A 2 (NVG vs Control) x 3 (targeted, distracters, mix of targeted and not) ANOVA of the mean categorical scores revealed a main effect of object type, $F(2,98) = 12.903$, $p<.001$. Multiple pair-wise comparisons with Bonferroni correction revealed that the mean number of correct scores of the control group were significantly higher for questions that involved 2 targeted objects ($M = .577$, $SE = .052$) compared to distracters ($M = .335$, $SE = .043$, $p< .05$) or a mix of both targeted and distracters ($M = .449$, $SE = .034$, $p< .05$). For the experimental group however there were no significant differences found between category means (see Figure 11). No significant differences between group means were found among all three categories.

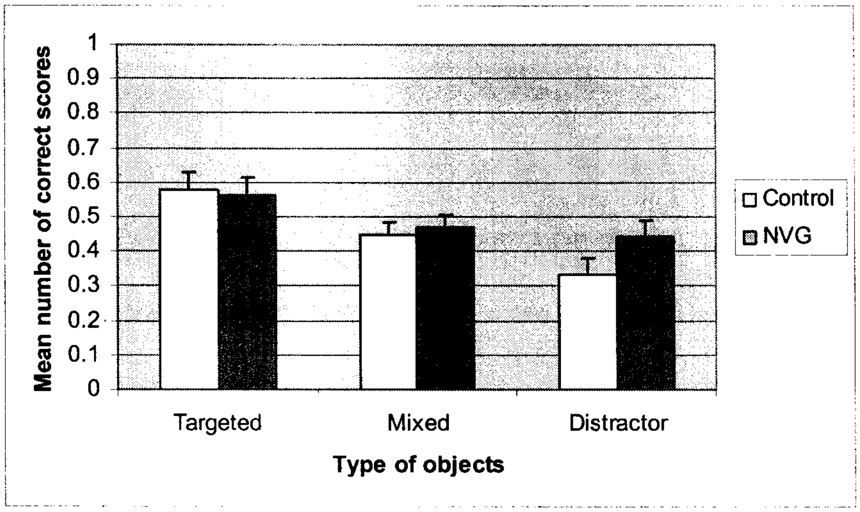



*Figure 11.* Mean number of correct scores (+SE) for the NVG and control group according to type of object.

In summary, participants in the control group were more accurate in answering questions related to 2 targeted objects compared to distracters or a mix of targeted and distracters. In the NVG group on the other hand, the type of object had no significant impact on participants' scores on the distance estimation task. In other words, whereas the knowledge about objects and of their location was a factor in the control groups' ability to correctly answer the question, such knowledge had no significant influence on the NVG groups' scores.

*Quantitative map drawing analysis: correct object placement.* To provide a measure of differences in cognitive maps for the experimental environment, drawn maps were scored according to relative object positioning (Billinghurst and Weghorst, 1995). Objects were scored according to whether they were correctly positioned in the proper room and properly positioned to the right or left relative to other objects and features drawn in the map (see Figure 5 for an example of the map). A relative positioning ratio was then calculated for each map:

$$\text{Ratio} = \frac{\text{Correctly placed objects}}{\text{Total number of object placed in the drawing}}$$

The relative object position ratio was used to compare across experimental and control groups.

MRT was not a significant covariate ($F<1$) and was thus excluded from the analysis. A One-Way ANOVA revealed a significant group difference for the object positioning ratios, $F(1,51) = 6.271$, $p<.05$. There was also a significant correlation between participants' relative object position ratio and participants' overall mean orientation deviation scores ($r = .377$, $p<.01$). This would suggest that a "significant object" positioning scores may be used as a simple absolute measure of map accuracy. It also implies that the sketch maps accurately represent the spatial knowledge stored in participants' mental representations of the experimental environment.

The ratios were then converted into a percentage of mean relative position scores. The control group placed 84.6% of the objects correctly whereas only 71.8% of the objects were correctly placed by participants in the experimental group.

*Quantitative map drawing analysis: number of drawn rooms.* During the map analysis procedure, a recurrent feature about the maps became evident. Some participants were drawing maps that were inconsistent with the number of rooms in the experimental environment. In particular, some participants would draw an extra room, for a total of 6 rooms rather than 5 as in the actual experimental environment (see Figure 12 for an example map sketches from each group). Therefore, the difference between groups on the number of rooms drawn in each map was investigated. The proportion of participants in the experimental group who drew 6 rooms was .31 (or 8 participants) whereas the proportion from the control group was only .07 (or 2 participants). The difference in proportions is significant, $\chi^2(1, N = 52) = 4.457, p < .05$.

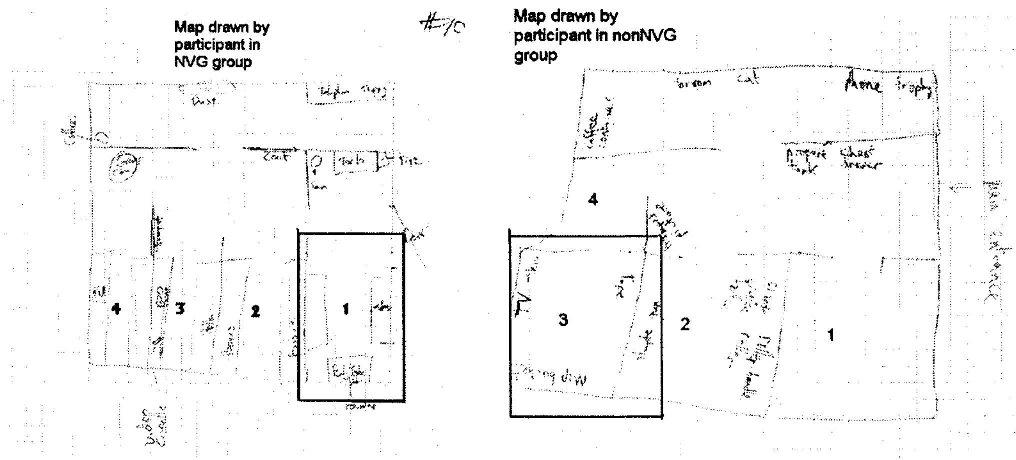



*Figure 12.* Example of map sketches by participants from each group. 5 out of 8 participants in the NVG group who drew an extra room drew maps with a room like the one shown in this figure, with similar proportions and in the same area (map on the left).

To investigate the possibility that spatial ability could have influenced the likelihood of drawing an extra room in the map, the difference between groups was investigated. The group that drew an extra room in their maps revealed an average MRT of 12.9 while the overall average MRT of all participants was 13.1. Therefore spatial ability did not appear to influence the systematic distortion of sketched maps in this particular group.

It is important to note that five out of the eight maps drawn with the extra room had the room located in the same area, with similar proportions. This was only seen in the experimental group. The extra room drawn by the two participants from the control group was different from each other and never the same as those drawn by participants in the experimental group.

*Qualitative map drawing analysis: map goodness scores.* To provide a measure of qualitative differences in cognitive maps for the experimental environment, maps were scored for goodness, similar to Billinghurst and Weghorst (1995). Three raters were recruited for this task. The objective of this task was to investigate if the goodness of a map drawn was impacted by wearing NVGs in the learning phase. Before map goodness could be related to group assignment, the degree of inter-rater reliability for the three raters was determined. Although the map goodness rankings are highly subjective, intraclass correlation analysis was significant, $F(50,102) = 3.919$, $p<.001$, indicating strong inter-rater reliability (Cronbach's alpha = .769).

Nonparametric Mann-Whitney U rank order test for two independent samples revealed that the NVG group tended to have worse goodness ratings for their map drawings as compared with the control group ($U=2367.500$, $p< .05$). See Figure 13 for frequency distributions of the map goodness ratings for the control group and the experimental group (rating 1 = very accurate, rating 5 = not accurate at all). As can be seen in Figure 13, the distribution of map goodness scores for the NVG group is skewed towards the lower ratings as opposed to the control group which exhibits a more normal distribution.

Finally, the relation between mean map goodness ratings and relative positioning ratio was investigated. Pearson Product Moment correlation was $r=.369$ ($p<.01$), indicating a relation between participants mean map goodness ratings and the proportion of objects placed correctly in the drawn maps. It also implies that the map goodness rating for the sketch maps is a good measure of map accuracy.

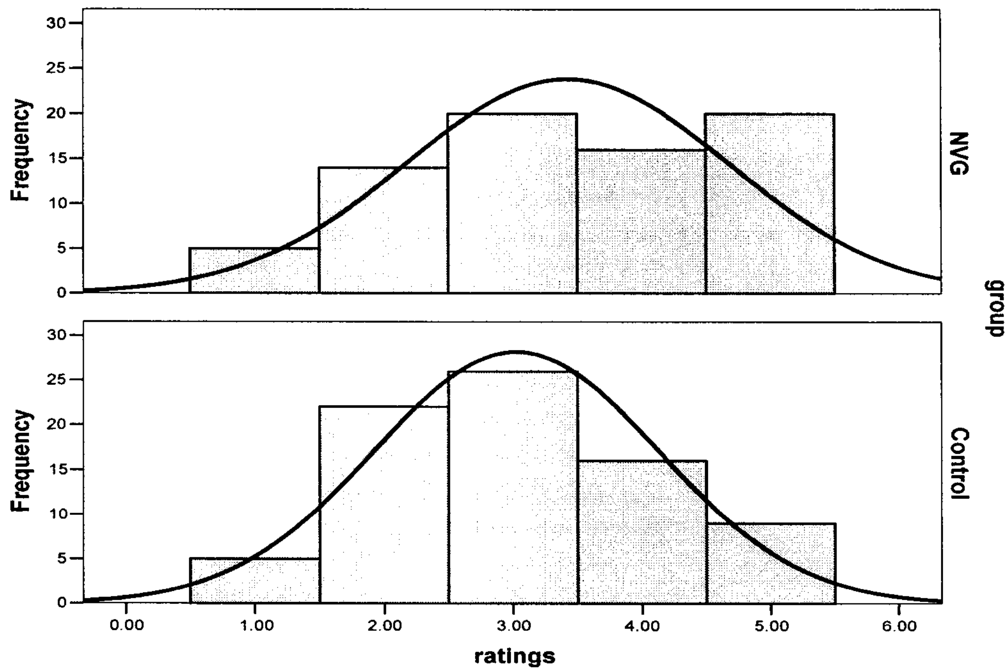



*Figure 13.* Frequency distributions of the map goodness ratings for the control group and the experimental group (rating 1 = very accurate, rating 5 = not accurate at all). The NVG group distribution is skewed towards the lower accuracy scores.

*Summary of survey knowledge tests.* As expected, participants in the control group performed better in the orientation and map drawing tasks compared to the NVG group. Performance in the orientation tasks was influenced by the type of object referred to in the task and the location of those objects. In the JRD task, the control group had significantly lower orientation deviation scores compared to the experimental group when the questions referred to two targeted objects located separate rooms and to two distracter objects located in the same room. Participants in the NVG group were also more likely to leave questions unanswered, particularly when the questions involved 2 distracter objects. In the distance estimation task, while there was no significant difference between groups in the number of correctly answered questions, the type of object referred to in the questions influenced participants' scores in the control group but not the NVG group. In the map drawing task, participants in the control group had significantly more objects correctly placed in their maps and better map goodness ratings compared to the NVG group. Participants in the NVG group were also more likely to draw an extra room than the control group. Unexpectedly, and most interestingly, 5 out of 8 of the extra rooms drawn were identical to each other in location and proportion. In summary, NVGs clearly had an impact on participant's performance in the orientation and map drawing tasks.

## Discussion

This thesis investigated the effects of using NVGs on the acquisition of spatial knowledge through active navigation and wayfinding. Specifically, the research addressed the following issues: (1) How do NVGs affect navigation and wayfinding performance? And (2) Do NVGs influence spatial learning and the acquisition of survey knowledge? The research approach used to investigate these issues was based on a typical learning paradigm involving two main phases. The first was a learning phase where users learned the environment through active navigation and exploration of a controlled environment with (experimental group) or without (control group) NVGs. In the second phase, the spatial knowledge acquired from the learning phase was tested with three spatial memory tasks: two orientation tests (relative pointing and distance estimation task) and a map drawing task.

The following chapter is organized as follows: A summary of the learning phase findings is presented followed by a summary of the test phase results. Theoretical accounts and practical implications of the results are then discussed.

*Navigation and wayfinding performance in the learning phase - Summary*

The results show that regardless of using NVGs or not, participants became quicker and more accurate in carrying out the search and wayfinding task as a function of search and wayfinding trials. Navigation and wayfinding performance, measured by navigation time, number of navigational, and unnecessary navigational turns, was worst at the beginning than at the end of the search and wayfinding trials. As practice progressed, participants became more efficient, i.e., taking less turns and less time in determining the route towards the target. The data gleaned from this investigation replicates previous research demonstrating that navigation performance improves with increased practice with the environment and the experimental task (see Thorndyke and Hayes-Roth, 1982; Gillner and Mallot, 1998; Parush and Berman, 2004; Blades, Lippa, Golledge, Jackson and Kitchin, 2002). Taken together, improved performance during the search and wayfinding task may reflect spatial learning which was tested later.

Results from the present investigation confirm the hypothesis that NVGs would impact wayfinding and navigation performance in the search and wayfinding task. The impact of NVGs was reflected in the navigation time, number of navigational turns and unessential turns taken during the learning phase. Participants using NVGs took significantly more time, more navigational turns and more unessential turns over the four blocks compared to participants not using NVGS.

As predicted, the rate of change in navigation and wayfinding performance over the 12 navigation trials was influenced by NVGs. Navigation times with NVGs decreased already in the second block compared to not wearing NVGs with a significant decrease only in the third block. Moreover, participants navigating without NVGs were navigating much quicker by the third block and very close to the minimum time required to reach the target. In contrast, participants navigating with NVGs demonstrated the greatest drop in navigation time between the first and second block, with a continuous significant decrease in navigation time over the remaining blocks, yet not reaching the minimum time required to reach the target by the end of the experiment.

Differences between the control group and the NVG group were also demonstrated in the number of navigational turns over the four blocks. Participants with NVGs had a significant drop in unessential navigation turns in the third block in comparison with the first block, and an increase in the fourth block. Participants without NVGs had a continuous decrease in unessential navigational turns until they were searching with close to the minimal required number of turns by the fourth block.

Taken together, the current results extend previous findings that implied NVGs may influence navigation and wayfinding and increase the risk of navigation errors (Johnson, 2004; Ruffner, Antonio, Joralmon, & Martin, 2004; Salazar, et al., 2003, McLean & Rash, 1999). In addition, the current findings support the established training programs that advocate extensive practice and training with NVGs under various operational conditions. These training programs expose users to a variety of scenarios that include spatial navigation and related cognitive processing. (US Army Safety Center, 1996; Johnson, 2004; Ruffner, Piccione, & Woodward, 2004). The results from the current study are the first to further clarify how NVGs might influence spatial navigation. By clarifying the nature of the impact of NVGs on spatial navigation and wayfinding, the current results provide empirical evidence beyond that of anecdotal reports.

In summary, findings of the present investigation indicate that NVGs had an effect on navigation and wayfinding performance during the learning phase. Participants' navigation performance improved over the course of the blocks, yet navigation performance and the pattern in which this performance progressed was influenced by whether NVGs were used or not.

*Degraded viewing conditions, attention demands and spatial learning*

The results clearly demonstrate that NVGs do impact the performance in the navigation and wayfinding task and how this performance progresses. This section addresses the questions: Why was wayfinding performance of NVG users different and poorer compared with those not wearing NVGs?

*Degradation of visual information.* Results from studies investigating the impact of vision on spatial tasks suggest that the poorer navigation performance of participants in the NVG group in this study may be attributable to degraded visual information. It has been reliably demonstrated that vision is the primary cue when experiencing the environment directly and facilitates navigation and wayfinding (e.g., Riecke, 2003; Reiser, Hill, Talor, Bradfield and Rosen, 1992). Visual space perception enables the detection and recognition of the direction and location of objects and landmarks in relation to the viewer and to each other (Wang and Spelke, 2002; Montello, in press: Diwadkar and McNamara, 1997; Sun et al., 2004) and permits the continuous monitoring of one's position within the environment using a variety of static and dynamic visual cues (Wang and Spelke, 2000; Loomis et al., 1993; Sun et al., 2004; Klatzky, Loomis, Beall, Chance, and Golledge, 1998). Under degraded visual conditions, when viewing the environment through viewing devices such as NVGs and HMDs, the informational content of the visual scene is reduced and was shown to affect the ability to encode and recognize the visual scene (Ventrino & Wells, 1990; Wells & Venturino, 1990; Niall, et al., 1999; Rash, & McClean, 1999). For example, a narrow FOV can reduce the number of landmarks available in the visual field demanding an increased need for head scanning (Geri, et al., 2002; Wells and Ventrino, 1990; Czerwinski, Tan & Robertson, 2002). Furthermore, increased head scanning and reduced landmark recognition may increase spatial disorientation (Antunano & Mohler, 1992; Klymenko, et al., 1999; Dolezal, 1982). Studies investigating the impact of NVGs and HMDs have found similar performance decrements in various spatial tasks (Gish, and Staplin, 1995; Klymenko, Harding, Beasley, Martin and Rash, 1999; Geri, et al., 2002; Niall, et al., 1999; Reising & Martin, 1990).

The data presented above would suggest that characteristics of NVGs that produced slightly degraded visual imagery relative to normal full-light day vision imagery including optical (e.g restricted FOV, decreased resolution), and electro-optical (e.g. scintillating noise) may have influenced the perception and recognition of the visual scene (i.e., landmarks and their relative position) thereby reducing participant's performance in the search and wayfinding tasks. Thus, NVGs can provide framework for investigating the influence of visual decrements on spatial cognition.

The performance findings of the present investigation extend previous research demonstrating that the altered visual effects produced by NVGs contribute to visual deficits and navigation performance. Indeed, participants who wore NVGs during the learning phase had more difficulty recognizing objects (verbal reports would testify to this) and navigating (e.g., trying to avoid running into walls). These participants, in addition to the search and wayfinding task, had the complex task of interpreting the distorted visual information through the viewing device. In other words, relative to the non-NVG group, they had more to learn. The rapid improvement early on in navigation performance implies that they quickly learned to compensate for the degraded visual conditions due to NVGs. They became more efficient in their task, which led to a significant decrease in unessential navigation turns in the third block. The learning curve was less dramatic for participants not using NVGs, in comparison, as they did not have as much to learn as the NVG group. In conclusion, the impaired performance seen in the

NVG group may therefore be attributed to the altered visual imagery (or degraded visual information) associated with NVGs.

*Role of attentional resources.* The notion of a possible additional task that NVG users had to learn and perform can be further expanded and combined with the notion of limited attention resources. NVGs appeared to influence how wayfinding performance level changed over continuous exposure to the environment. One possible explanation for the pattern in performance level changes could be attributed to a deficit in attention resources. Moray's (Moray, 1967) "central processor" model of attentional resources proposes that humans have a limited amount of attentional resources or capacity for processing information. It proposes that resources can be allocated to several tasks at one time as long as capacity is not exceeded. It has been shown that greater attention to visual perception is required when viewing the environment through viewing devices such as NVGs and HMDs (McLean & Rash, 1999; Salazar, Temme & Antonio, 2003; Riesing & Martin, 1995; Hale & Piccione, 1990). This may be attributed to the unnatural imagery produced by these devices. It has also been suggested that this increase in attentional resources may be at the expense of attentional resources needed for navigational tasks (Wickens, 2002; Czerwinski et al., 2002; Gish and Staplin, 1995; Allen and Willenborg, 1998; Horrey, Wickens, & Alexander, 2003). Conversely, a more natural visual scene can free up attentional resources utilized in improving performance of spatial tasks. For example, Czerwinski and colleagues (2002) found that women performed better on a navigation task within a 3D virtual environment with a wide FOV (75 degrees) compared to a narrow FOV (32.5). It was concluded that a wider field of view allowed the participants to perceive more visual information, demanding less head/eye movements thereby freeing up cognitive resources that might otherwise be engaged in navigation and wayfinding and acquiring knowledge of the environment. In light of this evidence, it is conceivable that, for the NVG group, the significant decrease in navigation times between the first and second block could be attributed to the fact that participants quickly got used to the new visual scene and thus became more efficient. They then could allocate more attentional resources for the navigation and wayfinding task at hand and they began to learn the environment better which led to a significant drop in unnecessary turns by the third block. Indeed, results from the subjective workload scores in this study showed the greatest decrease in scores occurred between the first and second block for the NVG group, then increasing over the third and fourth block. This suggests that the construct of attentional resources can also account for spatial navigation and wayfinding performance and spatial learning.

*Possible role of overconfidence.* Finally, unlike the non-NVG group, participants with NVGs began making more unessential turns in the fourth block. It has been speculated that NVG operators sometimes exhibit overconfidence with NVGs which may be implicated in an increase in the probability of errors in target detection and navigation (Uttal and Gibb, 2001, Ruffner, et al., 2004). Perhaps the increase in the fourth block in participants with NVGs is attributable to overconfidence of navigating with NVGs, resulting in decreased navigation and wayfinding performance. However, since confidence scores were not recorded, this account needs additional confirmation

In summary, the degraded visual information (an unnatural visual imagery) associated with NVGs could account for the performance differences between the NVG group and the control group in the search and wayfinding tasks. While participant's navigation and wayfinding performance improved over the four blocks, the pattern in which this performance improved may have been influenced, at least in part, by attentional resources and overconfidence.

Is it conceivable that those who navigated without NVGs may have learnt something different or additional than those who navigated with NVGs? As was seen in the navigation test, navigation performance in itself, and as will be discussed later with respect to the orientation and map drawing tests, the different patterns may also be possibly related to the acquisition of additional, and/or more accurate survey knowledge by those who learnt to navigate without NVGs. The implications of visual degradations due to NVGs for survey knowledge acquisition are discussed next.

*Summary of survey knowledge findings*

The effects of NVGs on the acquired survey knowledge were assessed following the learning/wayfinding phase. Three spatial memory tests were used to assess the accuracy and level of acquired survey knowledge: two orientation tests (JRD and distance estimation) and a map drawing task. In terms of the magnitude of the deviation from the correct direction of the target in the JRD task, there was a clear indication that both groups of participants tended to point closer to the correct direction when objects in the task were targets previously searched in the navigation task, or targeted objects, compared to distracters or a mix of both. This finding may imply that better spatial knowledge is associated with explicit learning of objects that were targets in the search tasks, as opposed to implicit learning of objects that were distracters in the search task.

Although JRD performance was generally better for targets in the search task, it depended on the use of NVGs and room location. There was no difference between groups for targeted objects when they were located in the same room. However, participants who did not wear NVGs during the learning phase tended to point closer to the correct direction of distracters located in the same room compared to participants with NVGS. In addition, participants who wore NVGs during the learning phase were more likely to leave questions unanswered when questions included two objects that were not targeted. Neither group left any question unanswered when both objects referred to targeted objects, indicating that they had enough knowledge about the orientation of those objects or of the objects themselves to answer the question. In addition, when the targeted objects were located in separate rooms, orientation accuracy was significantly higher for participants in the non-NVG group.

In the distance estimation task, participants the control group were significantly more more accurate in answering questions related to 2 targeted objects compared to distracters or a mix of targeted and distracters. This measurement is an additional support for the suggestion that better spatial knowledge is associated with objects explicitly learned; i.e., targeted objects in the search task Interestingly, the type of object had no significant impact on the experimental group's scores on the distance estimation task This finding may reflect the participant's inability to judge the relative distance between objects.

While the overall map drawings were surprisingly accurate, participants who wore NVGs during the learning phase were more likely to position objects incorrectly, to draw an extra room, and to receive worse scores for map goodness compared to participants who did not wear NVGs. Most striking of all were the systematic distortions in a number of rooms drawn by participants in the NVG group. A significantly large number of them (8 participants) drew an extra room, while 5/8 of those participants actually drew a room in the same area and with similar proportions. This pattern was not evident among participants without NVGs.

In summary, the control group did better in judging the relative distance between searched objects compared to distracters, in relative pointing to searched objects across rooms, and to distracters in the same room as compared with the NVG group. Finally, the NVG group were more likely to position more objects incorrectly, receive worst map goodness scores and draw an extra room compared to controls. A significant number of those in the NVG group who did draw an extra room drew the same room in the same area and with similar proportions.

*The possible impact of NVGs on level and accuracy of survey knowledge*

The results clearly demonstrate that participants wearing NVG did worse in the orientation and map drawing tasks. This section addresses the question: Why was the performance of NVG users in the survey knowledge tests different and poorer from those not wearing NVGs?

*Frame of reference.* The data implies that participants without NVGs had acquired additional implicit knowledge (i.e., distracters) compared to participants without NVGs, indicated by greater accuracy score in the JRD task for distracters located in the same room. In addition, participants in the control group demonstrated more accurate knowledge of searched targets compared to participants in the NVG group for objects located in separate rooms. Furthermore, the control group did better in judging the relative distance between searched objects compared to distracters in the distance estimation task. For the NVG group, there were no significant differences between objects in the distance estimation task. The difference among groups in the JRD and distance estimation task could be attributable to the type of Frame Of Reference (FOR) acquired and used during the learning phase. A FOR helps people orient themselves, gives them a 'sense of direction' and can provide the basis for several types of spatial relations (Kuipers, 1978; Kray, 2004). Frequently a FOR is required to unambiguously specify the location and/or direction of objects. FOR can help a person remember the exact positions of figures by anchoring figures in frames or shapes in space. An egocentric FOR refers to the knowledge which is tied to oneself and is dependent on the direction faced (real or imagined) within the environment (Kitchin, Blades and Golledge, 1997). As one becomes more familiar with the environment through active navigation and exploration, as opposed to learning from a map, this frame of reference progresses to a system which is independent of the person's orientation, referred to as an allocentric frame of reference (Kitchin et al., 1997; Tversky, 1981). Consequently, in an allocentric FOR, one can refer to objects in an environment from a survey perspective.

The choice of reference frame is presumably made on the basis of task requirements. An egocentric FOR is suited for maintaining a representation of space around oneself. An allocentric FOR is useful for representing a fixed environment and for encoding object to object relations (Bryant, 1992). To successfully answer questions related to objects located in separate rooms (as in the JRD task and distance estimation task), an allocentric FOR may be needed. In the present investigation participants who wore NVGs during the learning phase had difficulty answering questions related to objects located in separate rooms, evident by their poorer performance on the orientation tasks. A possible reason for the different and poorer performance on the JRD (for searched targets in separate rooms) and distance judgment tasks by the NVG group could be that participants who learned the environment with NVGs had difficulty forming an allocentric FOR. This could have contributed to the development of less accurate survey knowledge in the NVG group compared to controls.

*Systematic distortions.* When examining the map drawings, the impact of NVGs on the accuracy of participants' mental representation, and particularly survey knowledge, becomes more evident. Indeed, not only were the maps drawn by participants in the NVG group less accurate, but some exhibited systematic distortions. Systematic distortions in people's spatial mental representations have been reported by several authors (Tversky, 1981; 1993; Stevens and Coupe, 1978; Milgram and Jodelet, 1976; Byrne, 1979). For example, when elements are located relative to each other, they are remembered as more aligned relative to a reference frame than they actually are (Tversky, 1993). Consistent with this, a majority of people reject a veridical map in favour of a distorted one in which North and South America are placed closer to one above the other than they actually are (Tversky, 1981). The systematic distortion seen in the NVG group could be attributed to problems of alignment. When two or more figures are close by, according to the principle of perceptual organization, proximity, the figures may be grouped and oriented towards each other (Gogel, 1978). The tendency for two (or more) figures in an array to line up relative to one another is termed alignment (Tvsersky, 1981). When navigating the experimental environment in the present investigation, the space in the hallway next to the toolchest opens up into the baby room/bedroom (see Figure 5). The two rooms are aligned face to face to each other. One possible explanation for the systematic distortions in the maps could be that due to problems of alignment, the participants in the NVG group were integrating the two egocentric frames of references (baby room/bedroom and the portion the hallway next to the toolchest) into one. Since they knew from their search task that there were three rooms where they had to find objects, but that none of these rooms included a tool chest, they then added another room beside the one they had created. Anecdotal reports from NVG participants following the experiment support this. Future studies should include a formal verbal report or at least a questionnaire addressing these issues.

Tversky (1981; 1993) has suggested that distortions in people's mental representations of space may reflect many different kinds of knowledge structures, some that more accurately represent the real environment and are more consistent with images especially where environments are simple and well-learned (Kosslyn, 1980), while others are more like a "hodge-podge" of multi-modal collages especially when details of the environments are not known (Tversky, 1981). In many instances, especially for detail-poor environments, the information relevant to memory or judgment may be in different forms, some of them not maplike at all. Some of the information may be distorted as well. Tversky (1993) has suggested that in these cases, people's internal representations of space may more resemble *collages,* that is, a collection of successive visual scenes integrated into a mental representation of the traversed environment, which may contain some distortions. Tversky (1993) points out, however, that not all spatial knowledge is distorted, and some may be quite accurate. But even so, it is unlikely to be complete, so that problems can arise when trying to put it all together, especially when some of the information is erroneous. The poorer performance in the JRD task and the systematic distortions see in the map drawings of participants in the NVG group may suggest some erroneous spatial information in participant's memory which developed into a distorted mental representation of the environment.

Taken together, findings of the present investigation would suggest that NVGs had an effect on the level and accuracy of acquired survey knowledge. The differences between groups in the orientation tasks indicate that the development of frames of reference did not reach the same level. Indeed, the allocentric FOR in the NVG group appears to have been incomplete. The differences in map drawings between groups, meanwhile, indicate that the NVG group's mental representations of the environment may have been distorted.

*Integration of visual scenes and mental representations*

Why did the NVG group develop more distorted mental representations and an incomplete allocentric FOR? It has been suggested that mental representations and survey knowledge in particular, can be constructed from an integration of visual scenes acquired during wayfinding (Tversky, 1993; Czerwinski et al., 2002). This construction involves both the process of landmark-based navigation and dead-reckoning. Both static information (landmark-based navigation or piloting) and dynamic information (dead-reckoning), allow for the formation and use of mental representations of the environment through which travel and the planning of effective routes can take place. Landmark-based navigation involves determining one's current position within the environment by recognizing "visual scenes". These "scenes" are updated as one moves around in order to recognize the scene or localize an object from a different viewpoint. Landmark-based navigation is a common means of wayfinding in both familiar and novel environment. Dead-reckoning (originally from 'Deductive Reckoning') generally involves the process of updating or deducing one's current location with reference to a point of origin, relying on information about movement away from that point and has been suggested as a "glue" for the formation of spatial mental representations. Dead reckoning and landmark-based recognition therefore provide two sources of spatial information (e.g., static and dynamic) that may facilitate the formation of mental representation of the environment. It has been suggested that over successive encounters with an environment, where it is large enough that the navigator's viewpoint cannot encompass the environment in its totality, a sequence of local visual scenes and movements are integrated into a mental representation of the traversed environment (Gillner and Mallot, 2002; Czerwinski et al., 2002; Tvsersky, 1993).

Results from this investigation, in addition to various studies on spatial cognition, suggest that using NVGs during wayfinding degrades this process by reducing the informational content of each "visual scene", both in static (e.g., texture gradiant, accommodation, and FOV) and some dynamic (e.g., optic flow) cues. It has been suggested that when information in the visual scene is reduced, particularly when the FOV is restricted, the formation of spatial mental representations of unfamiliar places may result with decrements in the overlap of visual information across successive views (Czerwinski et al., 2002; Tversky, 1993). Evidence from other studies on FOV and spatial cognition can suggest that a reduced FOV may have particularly affected navigation and wayfinding performance in this investigation. Indeed, participants in the present investigation had to make more head movements and more navigation turns to allow better tracking of environmental information and spatial orientation. The need for additional attentional resources was also exhibited, particularly in the beginning. This is consistent with previous studies demonstrating that restricting FOV leads to perceptual, visual and motor decrements in various navigation and wayfinding tasks (Dolezal, 1982; Astur, Ortiz and Sutherland, 1990; Czerwinski et al., 2002). For instance, Dolezal (1982) reported that restricting the FOV to 12 degrees induced rapid head movements, difficulty in tracking objects and difficulty forming a cognitive map of unfamiliar places. He observed that there was a greatly reduced ability to integrate visual information across successive views. In light of these observations, a reduced FOV during navigation and wayfinding may impede the development survey knowledge by increasing the need to integrate more visual scenes into one mental representation and decreasing attentional resources for survey knowledge development. Taken together, narrower FOV in addition to limited attentional resources may be important factors in the formation of spatial mental representations by degrading the process of visual scenes integration during wayfinding.

In light of the findings in the present investigation, in addition to the literature review, it is reasonable to suggest that participants who wore NVGs during the learning phase had to integrate more visual scenes compared to participants who did not wear NVGs, resulting in an under-developed allocentric FOR and the development of distorted spatial mental representations. Taken together, the evidence presented above suggests that, a restricted visual scene, particularly a restricted FOV, may influence the formation of mental representations during wayfinding.

*Practical implications*

The use of NVGs contributes to the enhancement of military and civilian aviation operations, ground operations and maritime operations at night by increasing mobility, safety and mission effectiveness (Johnson, 2004; Ruffner, Piccione, and Woodward, 1997; Ruffner, Antonio, Joralmon, and Martin, 2004). While NVGs support and enhance visual perception in low-light or dark conditions, visual perception when using NVGS is different from un-aided visual perception in normal light conditions. Indeed, it has been clearly demonstrated that the various physical characteristics (e.g. optical and electro-optical) of NVGs influence not only visual perception but spatial cognition as well. Formal training and technological advancements have been used to overcome the limitations that the use of NVGs imposes.

Findings from field experiments and mishap and accident analyses suggest that problems experienced by NVGs users can often be attributed to a limited understanding of NVG capabilities and limitations, and to perceptual problems (Johnson, 2005). In addition, there are some indications that NVG knowledge and skills decay and require frequent practise in order to sustain them (Ciaverelli, Kishore, and Baer, 1994; Dyer and Young, 1998; Ruffner, Piccione and Woodward, 1997). A number of training techniques are recommended by various military training institutions (see Canadian Army, 2004) to allow users to interpret the unnatural imagery produced by NVGs. Some of these guidelines include identifying objects from their shapes and silhouettes, avoid rapid head or eye movements and maintain objects in the peripheral field of vision without staring at it for a prolonged period. These techniques are all strategies that help users to interpret and utilize an altered perception of naturalistic visual imagery. They can help identify landmarks, decrease disorientation and increase navigation and wayfinding. These skills are then maintained through practise. The results from present investigation justify and rationalize the current training protocols that help to maximize visual perception through

NVGs and that simple practice with NVGs improves navigation and wayfinding performance.

The current training protocols, however, do not consider how NVG characteristics, particularly that of a restricted FOV, may influence the formation of spatial mental representations. The findings of this study can be extended to improve training protocols so that more accurate spatial knowledge is formed with NVGs. The current results suggest that the Canadian forces and related organizations should adapt a formal training guideline with enhanced spatial navigation training. One possible strategy is to make NVG users aware of any inconsistencies in their mental representations. It has been found that inconsistencies in people's mental representations can be reduced when they are confronted with their inconsistencies (Baird, 1979; Baird, Merril and Tannenbaum, 1979). When people are asked for more information from an environment, they reconcile the inconsistencies in the correct direction and their judgments become more accurate (Tversky, 1993).

A way to implement this strategy would be to develop a simulated navigation and wayfinding training task with "pop quizzes" (see Parush, Ahuvia-Pick & Erev, 2005; Blades, Lippa, Golledge, Jacobson, & Kitchin, 2002). Such a strategy would require frequent testing of the NVG user's spatial knowledge. For instance, certain spatial tasks, such as relative pointing, verbalization or modelling (map drawing) could be performed during a search and locate task or free active exploration. These tests should be specially geared to facilitate the development of an allocentric FOR. For instance, relative pointing and distance judgement tasks would not only refer to objects close to the NVG user but also objects away from them, beyond walls and barriers. Corrective feedback could then be given to correct any inconsistencies in their memory that may exist. In addition, to facilitate implicit learning, many objects should be used in the tests, not just a select few. To facilitate better integration of visual scenes, the NVG user should be exposed to as many different viewpoints as possible.

To conclude, current training protocols should be modified to ensure the development of a good FOR and maximize the integration of visual scenes and increase the likely the development of a coherent spatial mental representation. The practical significance of results of the current investigation in conjunction with future research is in its potential contribution to the development of an efficient NVG usage training program.

*Limitations of Study*

This study revealed that NVGs impact navigation and wayfinding performance and the accuracy and level of survey knowledge acquired through direct experience with the environment. However, the findings in this study reflect those of male NVG users. While the majority of NVG users are men (Johnson, 2004; Braithwaite et al., 1998), it goes without saying that there are some female users. Research has shown that women and men differ in navigation strategy and spatial knowledge (Parush & Berman, 2004; Galea & Kimura, 1993; Czerwinski, et al., 2003). Indeed, it has been reliably shown that men outperform women when navigating, such as when learning from routes on paper (Galea & Kimura, 1993), or in a virtual environment (Sandstrom, Kaufman, & Huettel, 1998). However, women have a better memory for identity and location of landmarks within the navigated environment, whereas men have enhanced knowledge of the Euclidean properties of the environment (Galea & Kimura, 1993; Sandrom, et al., 1998).

For instance, Galea and Kimura (1993) found that male undergraduates outperformed women in route learning from a novel map, whereas women outperformed men in landmark recall. Taken together, it appears that men and women focus on different types of information within their environment. Women prefer a more landmark-based strategy, whereas men prefer a more configurational (Euclidean) strategy (Galea & Kimura, 1993).

Consistent with these observations, women perform as well as men in a virtual navigation when they are presented with a large visual scene and enhanced landmarks (Czerwinski, et al., 2003; Parush & Berman, 2004). For instance, Czerwinski et al., demonstrated that female navigation in a virtual world was similar to men when provided with a large field of view. The authors concluded that wider fields of view allow better tracking of environmental information and spatial orientation via head/eye movements. Since NVGs provide a restricted FOV, thereby reducing the amount of information in the visual scene (i.e., landmarks), the effects of NVGs on female navigation and spatial knowledge may be greater for women than for men. The methods used in this study, meanwhile, may be biased towards greater performance in men. Indeed, men have consistently outperformed women in the judgment of relative direction task (Galea & Kimura, 1993; Sandrom, et al., 1998). The methods used in the present investigation should be modified to include a landmark recognition task to test this assumption. In summary, while the results of the present investigation clearly demonstrate the effects of NVG on navigation and wayfinding and acquisition of spatial knowledge, one must be careful when generalizing these results to women. Indeed, there may be differential effects of NVGs on women navigation performance and acquisition of spatial knowledge.

The results of this study should also be interpreted with caution when generalizing it to experienced NVG users. The conclusions made in this study were based on novice NVG users who required additional attentional resources to interpret the distorted visual cues while walking. Walking in normal visual conditions usually requires little attention and is considered to be "automatic" (Montello, in press). Walking with NVGs, particularly when first learned, appeared to require attentional effort, thereby demanding explicit strategies. Explicit strategies have been defined as procedures that are conscious and intentional (Montello, in press). The application of these strategies, particularly when they are first learned and applied, requires attentional resources (Montello, in press). With increased practice, a task becomes more automatic, requiring less attentional resources. Indeed, it has been reliably shown that navigation performance improves with increased practice with the environment and the experimental task (see Thorndyke and Hayes-Roth, 1982; Gillner and Mallot, 1998; Parush and Berman, 2004; Blades, Lippa, Golledge, Jackson and Kitchin, 2002). Results from the present investigation revealed that NVG users quickly learned to navigate with NVGs and became more efficient. This would indicate that increased practice with NVGs resulted in a reduced demand for explicit strategies. The results of this study, therefore, need to be interpreted with caution. Experienced NVG users would already have had plenty of practice with NVG, potentially leaving much attentional resources towards the search and wayfinding task. Meanwhile, NVG experts are usually trained navigators – which also could impact navigation and wayfinding performance. Future navigation and wayfinding studies with NVGs should also investigate the impact of NVGs on experienced users and compare results to novice users.

Finally, there were no differences between the NVG and control group in the distance estimation task. Meanwhile, accuracy scores were just above the 50% for questions related to targeted objects and below 50% for distracters or a mix of both. These results indicate that participants' responses were barely above guess level for targeted objects and at guess level for the other two categories. It is unlikely that the poor performance in the distance estimation task is due to lack of survey knowledge. It is well documented that the knowledge of the inter-object Euclidean (i.e., straight-line target to target) distances (Thorndyke & Hayes-Roth, 1982; Loomis et al., 1996, Bigelow, 1996) is indicative of survey knowledge. It has also been shown that increased experience with an environment leads to improved performance on distance estimation task, indicating greater survey knowledge (Thorndyke & Hayes-Roth, 1982; Loomis et al., 1996, Bigelow, 1996). The distance estimation task used in the present investigation was adopted from the study by Bigelow (1996). In Bigelow's study, performance in the distance estimation task improved with increased experience within the environment, indicating increased survey knowledge. Rieser et al. (1992), employed a similar distance estimation task using triadic comparisons (closest together, farthest apart). As in the Bigelow (2003) study, performance in the distance estimation task improved with increased experience within the environment.

Performance on the distance estimation task in the present investigation was barely above guessing level, indicating that this task may not be a good measure of survey knowledge. The poor performance in this study is probably not due to lack of survey knowledge but how this task was assigned. In the study by Bigelow (2003) and Rieser et al (1992), participants had no time limit to make their distance estimation judgments. In current investigation, participants had a time limit of 15 seconds to make their distance judgments. This task required participants to recall 4 objects, their location, then make accurate estimations about their relative distance to each other. Fifteen seconds may not have given users enough time to do this task. Indeed, anectodal reports from participants following this task reported that much of their answers were a "guess". Likewise, pilot tests of this task were done as a paper and pencil test with unlimited time to finish the task. Judgments were quite accurate. In summary, while distance estimation tasks appear to be a reliable measure of survey knowledge, the method used in this study needs to be further explored. Future studies should apply this distance estimation task with unlimited time limits. This should give participants sufficient time to recall the objects referred to in the questions upon which they can then make their decisions.

*Future research agenda*

In current training protocols, NVG users often refer to a map of the environment prior to exploring it. There are indications that an allocentric FOR can be acquired independently of active exploration with the help of aids such as maps. For example, it was found that people who learned from maps were more accurate in estimating direct distances between pairs of points than those who learned the environment through actual exploration (Thorndyke and Hayes-Roth, 1982). It would be interesting to see if learning from a map would help develop an allocentric FOR. A future NVG study could evaluate NVG users learning from exploration only versus leaning with a map plus exploration. Meanwhile, the methodologies used in the present investigation should be refined to test FOR explicitly in order to determine what role it plays in the formation and use of spatial mental representations while using NVGs.

In the present investigation, navigation performance of participants in the NVG group never reached the optimal level achieved by the control group. It was not possible to indicate if navigation performance with NVGs would ever reach the same level of proficiency as navigation without NVGs. In order to investigate the learning of spatial knowledge, many studies have assessed performance on spatial tasks over time (Thorndyke and Hayes-Roth, 1982; Bigelow, 1996; Gillner and Mallot, 1998; Blades et al., 2002). A method often used is to assess how long it takes participants to learn an environment, determined by the number of trials needed to master some spatial task (i.e., no error rates in navigation and/or orientation performance). It would be interesting to see if it was possible to master navigation and wayfinding with NVGs and, if so, how long it would take compared to without NVGs. Future studies could possibly address this question by adopting similar methods as those mentioned above. In addition, a longitudinal study of navigation and wayfinding performance should be employed. The impact of NVGs on the acquisition of spatial knowledge could then be assessed at different times throughout the study.

While there was a clear demonstration of the impact of NVGs on wayfinding performance and the acquisition of spatial knowledge, the specific factors associated with NVGS on particular aspects of spatial cognition need to be isolated. The effects of the various physical characteristics of NVGs that can be considered as optical or electro-optical (e.g, restricted FOV, monochrome vision, scintillating noise, etc) should be characterized. Future navigation and wayfinding studies should isolate the effects of static and dynamic visual cues on spatial cognition. For instance, it would be interesting to see the effects of restricted FOV on spatial cognition compared to NVGs and a control.

And finally, attentional resources and operator confidence were two other possible factors involved in the differences in performance between groups. Future studies with NVGs and HMDs should investigate the possible influence of attentional resources and operator confidence on spatial cognition.

NVGs and HMDs will continue to be developed for future use. The methodology used in this study can serve as a basic experimental paradigm in testing the development of these new technologies. Our interest is to further training methodologies and the development of technology. Human factors and usability methods will be vital for improved technological advancements and future training programs.

References

Allen, G.L., & Willenborg, L.J. (1998). The need for controlled information processing in the visual acquisition of route knowledge. *Journal of Environmental Psychology, 18*(4), 419-427.

Alphano, P.L. & Michel, G.F. (1990). Restricting the field of view: perceptual and performance effects. *Perceptual and Motor Skills, 70,* 35-40.

Arthur, K.W. (2000). *Effect of field of view on performance with head mounted displays.* Unpublished Doctoral Dissertation, Department of Computer Science, University of Carolina, Chapel Hill.

Astur, R. S., Ortiz, M. L., & Sutherland, R., J. (1998). A characterization of performance by men and women in a virtual Morris water task: A large and reliable sex difference. *Behavioural Brain Research, 93,* 185-90.

Aviram, G. & Rotman, S.R. (1999). Evaluating the effect of infrared image enhancement on human target detection performance and image quality judgment. *Optical Engineering, 38*(8), 1433-1440.

Baird,J. (1979). Studies of the cognitive representation of spatial relations: I. Overview. *Journal of Experimental Psychology: General, 108*, 90-91.

Baird,J., Merril,A., & Tannenbaum, J. (1979). Studies of the cognitive representations of spatial relations:II. A familiar environment. *Journal of Experimental Psychology: General, 108,* 92-98.

Barber, A.V. (1990). Visual mechanisms and predictors of far field visual task performance. *Human Factors, 32*(2), 217-233.

Bigel, M. G., & Ellard, C.G. (2000). The contribution of nonvisual information to simple place navigation and distance estimation: An examination of path integration. *Canadian Journal of Experimental Psychology, 54*(3), 172-184.

Bigelow, A. E. (1996). Blind and sighted children's spatial knowledge of their home environments. *International Journal of Behavioral Development, 19*(4), 797-816.

Billinghurst, M., & Weghorst, S. (1995). The use of sketch maps to ensure cognitive maps of virtual environments. *Proceedings of Virtual Reality Annual International Symposium, VRAIS, 1995,* 40-47.

Blades, M. (1990). The reliability of data collected from sketch maps. *Journal of Experimental Psychology, 10*, 327-339.

Blades, M., Lippa, Y., Golldedge, G., Jacobson, R.D., & Kitchen, R.M. (2002). The effect of spatial tasks on visually impaired people's wayfinding abilities. *Journal of Visual Impairment & Blindness, 96*, 407-419.

Braithwaite, M.G., Douglass, P.K., Durnford, S.J, & Lucas, G. (1998). The hazard of spatial disorientation during helicopter flight using night *vision devices. Aviation, Space and Environmental Medicine, 69,* 1038-1044.

Braithwaithe, M. G., Durnford, S. J., Crowley, J. S., Rosado, N. R., & Albano, J. P. (1998). Spatial disorientation in US Army rotary-wing operations. *Aviation, Space, and Environmental Medicine, 69,* 1031-1037.

Braunstein, M. L. (1976). *Depth perception through motion.* New York NY: Academic Press.

Bryant, D. J. (1992). A spatial representation system in humans. Retrieved July, 2005, from http://psycprints.ecs.soton.ac.uk/perl/local/psyc/makedoc?id=240&type =html.

Byrne, R.W. (1979). Memory for urban geography. *Quarterly Journal of Experimental Psychology, 15,* 73-86.

Canadian Army (2004). *Armour School Master Lesson Plan, Armored Reconnaissance Specialist Course: Observation.*

Ciavarelli, A., Kishore, A. S., and Baer, W. (1994). *Night vision goggle training technology* (Technical Report). Monterey, CA: Naval Postgraduate School

Creem-Regehr, S.H., Willemsen, P., Gooch, A.A., & Thompson,W.B. (2003). *The Influence of Restricted Viewing Conditions on Egocentric Distance Perception: Implications for Real and Virtual Environments* (Technical Report No. UUCS-03-016). Utah, Salt Lake City: University of Utah, Department of Psychology.

Cutting, J.E. (1986). *Perception with an eye for motion.* Cambridge, MA: MIT Press.

Cutting, J. E. (1997). How the eye measures reality and virtual reality. *Behaviour research Methods, Instruments, and Computers, 29,* 27-36.

Cutting, J. E., Vishton, P. M., & Braren, P. A. (1995). How we avoid collisions with stationary and with moving obstacles. *Psychological Review, 102*, 627-651.

Cuqlock-Knopp, V.G., & Whitaker, L.A. (1993). Spatial ability and land navigation under degraded visual conditions. *Human Factors, 35*(3), 511-520.

Czerwinski, M., Tan, D.S., & Robertson, G.G. (2002). Women take a wider view. *Proceedings of the Conference on Human Factors in Computing Systems (CHI), 2002, 4*(1), 195-202.

Darken, R.P., Allard, T. & Achille, L.B. (1998). Spatial orientation and wayfinding in large-scale virtual spaces: An introduction [Electronic version]. *Presence, 7*(2), 101-107.

Darken, R.P., & Peterson, B. (2002). Spatial orientation, wayfinding, and representation. In K. M. Stanney (Ed.), *Handbook of Virtual Environments: Design, Implementation, and Applications* (pp. 493-518). Mahwah, NJ: Lawrence Erlbaum Associates.

Darken, R. P. & Sibert, J. L. (1996). Wayfinding strategies and behaviors in large virtual worlds. *Proceedings of the Conference on Human Factors in Computing Systems (CHI),* 49-72.

DeLucia, P.R. (1999). Critique of "distance estimation with night vision goggles: a little feedback goes a long way". *Human Factors, 41*(3), 507-510.

Dijkerman, H.C., Milner, A.D. & Carey, D.P. (1996). The perception and prehension of orientation in the depth plane. I. Effects of visual form agnosia. *Experimental Brain Research, 112,* 442-451.

Dijkerman, H.C., Milner, A.D., & Carey, D.P. (1999). Motion parallax enables depth processing for action in a visual form agnosic when binocular vision is unavailable. *Neuropsychologia, 37*(13), 1505-10.

Diwadkar, V.A. & McNamara, T.P. (1997). Viewpoint dependence in scene recognition. *Psychological Science, 8*(4), 302-307.

Docherty, D., Van-Gyn, G.H., & Falkenberg, L. (1986). Developmental aspects of organizational strategies in recall of extent of movement. *Perceptual and Motor Skills, 62*(3), 919-922.

Dodds, A.G., Howarth, C.I., & Carter, D.C. (1982). The mental maps of the blind: The role of previous visual experience. *Visual Impairment and Blindness, 76*, 5-12.

Dolezal, H. (1982). *Living in a world transformed: perceptual and performatory adaptation to visual distortion*. New York: Academic Press.

Durgin, F.H., Fox, L.F., Lewis, J., & Walley, K.A. (2002). *Perceptuomotor adaptation: more than meets the eye.* Poster presented at the 43rd Annual Meeting of the Psychonomic Society, Kansas City, MO.

Dyer, J. L., and Young, K. M. (1998). *Night vision goggle research and training issues for ground forces: A literature review.* Alexandria, VA: US Army Research Institute.

Edgar, G.H., Pope, J.C.D., & Craig, I.R. (1994). Visual accommodation problems with head-up and helmet-mounted displays? *Displays, 15*(2), 68-75.

Edwards, G., Thompson, J., & MacGregor, C. (1998). Investigating the role of guided tours in virtual reality environments. *Proceedings of the Human Factors Association of Canada, Missausauga, Ontario, 1,* 1-4.

Foley, J.M. (1980). Binocular distance perception. *Psychological Review, 87,* 411-434.

Galea, L. A. M. & Kimura, D. (1993). Sex differences in route learning. *Personality and Individual Differences, 14*, 53–65.

Gallistel, C.R. (1990). *The organization of learning.* Cambridge, MA: MIT Press.

Geri, G.A., Martin, E.L., & Wetzel, P.A. (2002). Head and eye movements in visual search using night vision goggles. *Aviation, Space, Environmental Medicine, 73*(8), 779-786.

Gillner, S., & Mallot, H.A. (1998). Navigation and acquisition of spatial knowledge in a virtual maze. *Journal of Cognitive Neuroscience, 10*(4), 445-463.

Gogel, W. C. (1978). The adjacency principle in visual perception. *Scientific American, 238*(5):126-39.

Goldin, S.E., & Thorndyke, P.W. (1982). Simulating navigation for spatial knowledge acquisition. *Human Factors, 24*(4), 457-471.

Hale, S., & Piccione, D. (1990). *Pilot performance assessment of the AH-64 helmet display unit* (Technical Note 1-90). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory.

Henry, D. (1992). *Spatial perception in virtual environments: evaluating and architectural application.* Master's thesis, University of Washington. Retrieved October, 2004, from http://www.hitl.washington.edu/publications/henry/thesis-introduction.html.

Hettinger, L.J., Nelson, W.T., & Haas, M.W. (1996). Target detection performance in helmet-mounted and conventional dome displays. *International Journal of Aviation and Psychology, 6*(4). 321-34.

Hintzman, D.L., O'Dell, C.S., & Arndt, D.R. (1981). Orientation in cognitive maps. *Cognitive Psychology, 13,* 149-206.

Hirtle, S. C., & Kallman, H. K. (1988). Memory for the location of pictures: Evidence of hierarchical clustering. *American Journal of Psychology, 101,* 159-170.

Holding, C.S. & Holding, D.S. (1989). Acquisition of route network knowledge by males and females. *Journal of General Psychology, 116*(1), 29-41.

Holway, A. H. and Boring, E. G. (1941). Determinants of apparent visual size with distance variant. *American Journal of Psychology, 54,* 121-151.

Horay, W.J., Alexander, A.L., & Wickens, C.D. (January, 2003). *Does workload modulate the effects of in-vehicle display location on concurrent driving and side task performance?* (Tech. Rep. No. AHFD-0301/GM-03-1). Savoy, Illinois: Aviation Human Factors Division: Institute of Aviation.

Hughes, M.F. & Takallu, M.A. (n.d.). *Terrain portrayal for head-down displays experiment.* Retrieved October, 2004, from http://techreports.larc.nasa.gov/ltrs/PDF/2002/mtg/NASA-2002-iaatc-mfh.pdf.

Jacobson, R.D. (1998). Cognitive mapping without sight: four preliminary studies of spatial learning. *Journal of Experimental Psychology, 18*, 289-305.

Jennings, S., Craig, G. (2000). Theoretical issues relevant to helmet-mounted display attitude symbology. *Proceedings of the Society of Photo-Optical Instrumentation Engineers Proceedings (SPIE), 4021,* 294-301.

Johnson, Chris. (2004). *The role of night vision equipment in military incidents and accidents.* Retrieved August, 2005, from http://www.dcs.gla.ac.uk/~johnson/papers/night_accidents.pdf.

Kamil, A. C. and Jones, J. E. (2000). Geometric rule learning by Clark's nutcrackers (*Nucifraga columbiana*). *Journal of Experimental Psychology: Animal Behavior Processes, 26*(4), 439-453.

Kitchin, R.M., Blades, M. & Golledge, R.G. (1997). Understanding spatial concepts at the geographic scale without the use of vision. *Progress In Human Geography, 21* (2), 225-242

Klatzky, R.L., (1998). Allocentric and egocentric spatial representations: Definitions, distinctions, and interconnections [electronic version]. In C. Freska, C. Habel & K.F. Wender (Eds.), *Spatial cognition- An interdisciplinary approach to representation and processing of spatial knowledge* (Lecture Notes in Artificial Intelligence 1404). (pp. 1-17). Berlin: Springer –Verlag. Retrieved September, 2004, from http://www.psy.cmu.edu/faculty/klatzky/allo_ego.pdf.pdf.

Klatzky, R.L., Loomis, J.M., Beall, A.C., Chance, S.S., and Golledge, R.G. (1998). Spatial updating of self-position and orientation during real, imagined, and virtual locomotion [Electronic Version]. *Psychological Science, 9*(4), 293-298.

Kline, P.B., & Witmer, B.G. (1996). Distance perception in virtual environments: effects of field of view and surface texture at near distances. *Proceedings of the HFES 40th annual meeting, Philadelphia, PA,* 112-116.

Klymenko, V., Harding, T.H., Beasley, H.H., Martin, J.S., & Rash, C. (September, 1999). *The effects of helmet mounted display field-of-view configurations on target acquisition.* (Tech. Rep. No. 99-19). Frederick, MD: U.S. Army of Aeromedical Research Laboratory.

Knight, K.K, Apsey, D.A., Jackson, W.G., & Dennis, R.J. (1998). A comparison of stereopsis with anvis and F4949 night vision goggles. *Aviation, Space, Environmental Medicine, 69,*(2), 99-103.

Kray, C. (2004). Inducing frames of reference. Workshop on Spatio-Temporal Reasoning. *Proceedings of the 16th European Conference on Artificial Intelligence (2004), ECAI,* Valencia: Spain.

Kuyk, T., Elliott, J.L., & Fuhr, P.S. (1998). Visual correlates of obstacle avoidance in adults with low vision. *Optometry and Vision Sciences, 75*(3):174-182

Kuipers, B.J. (1978). Modelling spatial knowledge. *Cognitive Science, 2*, 129-153.

Loomis, J.M., DaSilva, J.A., Philbeck, J.W., & Fukusima, S.S. (1996). Visual perception of location and distance. *Current Directions in Psychological Science, 5*(3), 72-77.

Loomis, J.M., Klatzky, R., Golledge, R.G., Cicinello, J.G., Pellingrino, J.W., & Fry. P.A. (1993). Nonvisual navigation by blind and sighted: Assessment of path integration ability. *Journal of Experimental Psychology, 122*(1), 73-91.

Loomis, J.M., Klatzky, R.L., Golledge, R.G., & Philbeck, J.W. (1999). Human navigation by path integration. In R.G. Golledge (Ed.), *Wayfinding behaviour: cognitive mapping and other spatial process* (pp. 125-151). Baltimore, MD: Johns Hopkins Press.

Loomis, J. M., & Knapp, J. M. (2003). Visual perception of egocentric distance in real and virtual environments. In L. J. Hettinger, & M. W. Haas (Eds.), *Virtual and adaptive environments* (pp 21-46). Mahwah, NJ: Lawrence Erlbaum Associates.

Madden, D.H. & Allen, P.A. (1995). Aging and the speed/accuracy relation in visual search: evidence for an accumulator model [Abstract]. *Optometry and Vision Science, 72*(3), 210-216.

Magliano, J.P., Cohen, R., Allen, G.L. & Rodrigue, J.R. (1995). The impact of a wayfinder's goal on learning a new environment: Different types of spatial knowledge as goals. *Journal of Experimental Psychology, 15,* 65-75.

Mallot, H.A., & Gillner, S. (2000). Route navigation without place recognition: What is recognised in recognition-triggered responses. *Perception, 29,* 43-55.

McLean, W.E., & Rash, C.E. Visual performance. In C.E. Rash (Ed.). *Helmet mounted displays: design issues for rotary-wing aircraft.* Retrieved September, 2004, from http://www.usaarl.army.mil/hmdbook/cp_006.htm#cont6.5.

McLean, W. E., Rash, C. E., McEntire, J., Braithwaite, M. G., & Mora, J. C. (1997). A performance history of AN/PVS-5 and ANVIS image intensification systems in U.S. Army aviation. *Helmet- and Head-Mounted Displays II, Proceedings of SPIE, 3058,* 264- 298.

McNamara, T.P., Ratcliff, R., & McKoon, G. (1984). The mental representation of knowledge acquired from maps. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10,* 723-732.

McNamara, T.P. (1986). Mental representation of spatial relations. *Cognitive Psychology, 18,* 87-121.

Milgram, S., & Jodelet, D. (1976). Psychological maps of Paris. In Proshansky, H., Ittelson, W., Rivlin, L. (Eds.), *Environmental Psychology, 2nd* (pp. 104-112). New York: Holt, Rinehart and Winston.

Moffat, S.D., Hampson, E., & Hatzipanteli, M. (1998). Navigation in a 'virtual' maze: sex differences and correlation with psychometric measures of spatial ability in humans. *Evolution and Human Behavior, 19*(2), 73-87.

Montello, D.R. (in press). Navigation. In A. Miyake & P. Shah (Eds). *Cambridge handbook of visuospatial thinking.* Cambridge: Cambridge University Press.

Mon-Williams, M., Tresilian, J. R., McIntosh, R. D., & Milner, A. D. (2001). Monocular and binocular distance cues: insights from visual form agnosia. *Experimental Brain Research, 139*, 127-136.

Moray, N. (1967). Where is attention limited? A survey and a model. *Acta Psychologica, 27,* 84-92.

Nakayama, K., & Loomis, J.M. (1974). Optical velocity patterns, velocity sensitive neurons, and space perception: a hypothesis. *Perception, 3*, 63-80.

Niall, K.K., Reising, J.D., & Martin, E.L. (1999). Distance estimation with night vision goggles: a little feedback goes a long way. *Human Factors, 41*(3), 495-506.

Oen, F.T., Lim, T.H., & Chung, M.P. (1994). Contrast sensitivity in a large adult population [Abstract]. *Annals Academy of Medicine Signapore, 23*(3), 322-326.

Parsons, L. M. (1987). Imagined spatial transformation of one's body. *Journal of Experimental Psychology: General, 116*(2), 172-191.

Parush, A. & Berman, D. (2004). Navigation and orientation in 3D user interfaces: the impact of navigational aids and landmarks. *International Journal of Human-Computer Studies, 61,* 375-395.

Parush, A., Ahuvia-Pick, S., & Erev, I. (2005). Acquiring spatial knowledge with automatic navigation systems. Manuscript in preparation.

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenberg and Kuse mental rotations test: different versions and factors that affect performance. *Brain and Cognition, 28*, 39-58.

Philbeck, J.W., Loomis, J.M., & Beall, A.C. (1997). Visually perceived location is an invariant in the control of action. *Perception & Psychophysics, 59*(4), 601-612.

Piantanida, T.P. Boman, D., Larimer, J., Gille, J., & Reed, C. (1992). Studies of the field of view/resolution tradeoff in virtual reality. *Proceedings of Human Vision, Visual Processing, and Digital Display III, The International Society for Optical Engineering (SPIE),1666,* Bellingham, WA.

Pinkus, A. & Task, L. (1998). Measuring observer's visual acuity through night vision goggles. *SAFE Symposium Proceedings 1998, 36th Annual Symposium,* 1-11. Retrieved January, 2005, from www.hec.afrl.af.mil/Publications/VisAcu.pdf.

Radvansky, G.A., Carlson, R., Laura, A., & Irwin, D.E. (1995). Uncertainty in estimating distances from memory. *Memory and Cogniton, 23*(5), 596-606.

RCA Electro-optics handbook (1974). *Technical series EOH-11.* RCA Solid State Division, Electro-optics and Devices, Lancaster: RCA Corp.

Riecke, B.E. (2003). How far can we get with just visual information? Path integration and spatial updating studies in Virtual Reality (Doctoral Dissertation: Fakultät für Mathematik und Physik). *Dissertation Abstracts International, 47, 10243.* Retrieved September, 2004, from http://w210.ub.uni-tuebingen.de/dbt/volltexte/2003/999/pdf /thesis_final.pdf

Riecke, B.E., Van Veen, H.A.H.C., & Bulthoff, H.H. (2002). Visual homing is possible without landmarks: a path integration study in virtual reality. *Presence: Teleoperators and Virtual Environments, 11,* 443-473.

Riecke, B.E., von der Heyde, M., & Bulthoff, H.H. (2002). Spatial updating in virtual environments: What are vestibular cues good for? *Journal of Vision, 2,* 421a. Retrieved September, 2004, from http://journalofvision.org/2/7/421.

Rieser, J.J., Guth, D.A., & Hill, E.W. (1986). Sensitivity to perspective structure while walking without vision. *Perception, 15,* 173-188.

Rieser, J.J., Hill, E.W., Talor, C.R., Bradfield, A., & Rosen, S. (1992). Visual experience, visual field size, and the development of nonvisual sensitivity to the spatial structure of outdoor neighborhoods explored by walking. *Journal of Experimental Psychology: General, 121*(2), 210-221.

Reising, M. & Martin, E.L. (1995). *Distance estimation training with night vision goggles under low illumination* (Tech. Rep. No. AL/HR-TR-1994-0138). Dayton, OH: University of Dayton Research Institute.

Roberts, S., Parush, A. & Lindgaard, G. (in press). Cognitive theories and aids to support navigation of multimedia information space. In R. F. Taylor (Ed.): *Cybercartography: Theory and Practice.* Forthcoming by Elsevier.

Rogers, B. & Graham, M. (1979). Motion parallax as an independent cue for depth perception. *Perception, 8,* 125-134.

Rowland, J.H. (1999). The effects of texture on distance estimation in synthetic environments (Master's Thesis, Naval Postgraduate School, 1999). Retrieved October, 2004, from ttp://www.movesinstitute.org/darken/alumni/Rowland/ Rowland.PDF.

Ruffner, J.W., Antonio, J.D., Joralmon, D.Q., & Martin, E. (2004) Night vision goggle training technologies and situational awareness. *Proceedings of the Advanced Technology Electronic Defense System (ATEDS) Conference / Tactical Situational Awareness (SA) Symposium*, San Diego, CA.

Ruffner, J.W., Piccione, D., & Woodward, K. (1997). Development of a night driving simulator concept for night vision image intensification device training. *Proceedings of the Enhanced and Synthetic Vision Conference, SPIE 11th Annual International Symposium on Aerospace/Defense Sensing, Simulation, and Controls, 3088*, 190-197.

Salazar, G., Temme, L. & Antonio, J.C. (2003). Civilian use of night vision goggles. *Aviation, Space, and Environmental Medicine, 74*(1), 79-84.

Sanders, B., Wilson, J. R. & Vandenberg, S. G. (1982). *Handedness and spatial ability. Cortex, 18,* 79-90

Sandstrom, N. J., Kaufman, J., & Huettel, S. A. (1998). Males and females use different distal cues in a virtual environment navigation task, *Cognitive Brain Research*, *6*, 351–360.

Seamon, J.G., Ganor-Stern, D., Crowley, M.J., Wilson, S.M., Weber, W.J., O'Rourke, C. & Mahoney, J.K. (1997). A mere exposure effect for transformed three-dimensional objects: Effects of reflection, size, or color changes on affect and recognition. *Memory and Cognition, 25*(3), 367-374.

Sheehy, J.B. & Wilkinson, M. (1989). Depth perception after prolonged usage of night vision goggles. *Aviation, Space, Environmental Medicine, 60,* 573-579.

Shelton, A.L., & Gabrieli, J.D.E. (2004). Neural correlates of individual differences in spatial learning strategies. *Neuropsychology, 18*(3), 442-449.

Siegel, A. & White, S. (1975). The development of spatial representations of large-scale environments. In H. Reese (Ed.), *Advances in Child Development and Behavior* (pp. 9-25). New York: Academic Press.

Simons, D.J., & Wang, R.F. (1998). Perceiving real-world viewpoint changes. *Psychological Science, 9,* 315-320.

Stevens, A., & Coupe, P. (1978). Distortions in judged spatial relations. *Cognitive Psychology, 10,* 422-437.

Sun, H.J., Campos, J.L., Young, M., & Chan, G.S.W. (2004). The contribution of static visual cues, nonvisual cues, and optic flow in distance estimation. *Perception, 33,* 49-65.

Sun, H.J. & Frost, B.J. (1998). Computation of different optical variables of looming objects in pigeon nucleus rotundus neurons. *Nature Neuroscience, 1,* 296-303.

Task, H.L. (1997). HMD image source, optics, and the visual interface. In J.E. Mezler & K. Moffitt (Eds.), *Head Mounted Displays: Designing for the User* (pp.55-82). New York, NY: McGraw-Hill.

Thuresson, M., Ang, B., & Harms-Ringdahl, K. (2003). Neck muscle activity in helicopter pilots: effects of position and helmet-mounted equipment. *Aviation, Space, and Environmental Medicine, 74*(5), 527-579.

Tolman, E.C. (1948). Cognitive maps in rats and men. *Psychological Review, 55,* 189-208.

Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology, 14,* 407-433.

Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental model. In Frank, A.U. and Campari, I., (Eds.), *Spatial Information Theory: A theoretical Basis for GIS* (pp. 14-24). Berlin: Springer-Verlag.

US Army Safety Centre, U.S. (January, 2004) *Army Accident Information, Aviation Accident Statistics for the Current Fiscal Year.*

U.S. Department of Transportation, National Highway Traffic Safety Administration. (October, 1996). *Heavy vehicle driver workload assessment. Task 1: Task analysis data and protocols review.* Retrieved November, 2004, from http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/lq01!.pdf.

Uttal, W.R., & Gibb, R,W. (2001). On the psychophysics of night vision goggles. In R. Hoffman, A. B. Markman (Eds.). *Interpreting Remote Sensing Imagery: Human Factors* (pp.). Boca Raton, Florida: Lewis Publishers.

Vandenberg, S. G., & Kuse, A.R. (1978). Mental rotation, a group test of three-dimensional spatial visualization. *Perceptual & Motor Skills, 47,* 599-604.

Vinson, N.G. (1999). Design guidelines for landmarks to support navigation in virtual environments. *Proceedings of CHI '99 Papers, 15-20 May*, 278-285.

Voyer, D., Nolan, C., & Voyer, S. (2000). The relation between experience and spatial performance in men and women. *Sex Roles, 43,* 891-915.

Vyrnwy-Jones, P. (1988). *Disorientation accidents and incidents in U.S. Army helicopters, 1 Jan 1980 - 30 Apr 1987* (USAARL Report No. 98-3). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Waller, D., Loomis, J.M., Golledge, R.G., & Beall, A.C. (2000). Place learning in humans: The role of distance and direction information. *Spatial Cognition and Computation, 2,* 333-354.

Wang, R.F., & Simons, D.J. (1999). Active and passive scene recognition across view. *Cognition, 70*(2), 191-210.

Wang, R.F. & Spelke, E.S. (2002). Human spatial representation: insights from animals. *Trends in Cognitive Sciences. 6*(9), 376-381.

Warren, W.H., & Hannon, D.J. (1990). Eye movements and optical flow. *Journal of the Optical Society of America A,* 7, 160-169.

Wells, M.J., & Venturino, M. (1990). Performance and head movements using helmet-mounted display with different sized field-of-view. *Optical Engineering, 29,* 870-877.

Wickens, C. D. (1989). Resource management and time sharing. In, J. I. Elkind, S. K. Card, J. Hochberg and B. M. Huey (Eds.), *Human Performance Models for Computer-Aided Engineering* (pp. 180-202). Washington, DC, USA: National Academy Press.

Wickens, C.D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science,* 3(2), 159-177.

Young, M. The pinhole camera: Imaging without lenses or mirrors (December, 1989). *The Physical Teacher,* (pp. 648-655). Retrieved August, 2005 from http://www.mines.edu/~mmyoung/PHCamera.pdf.

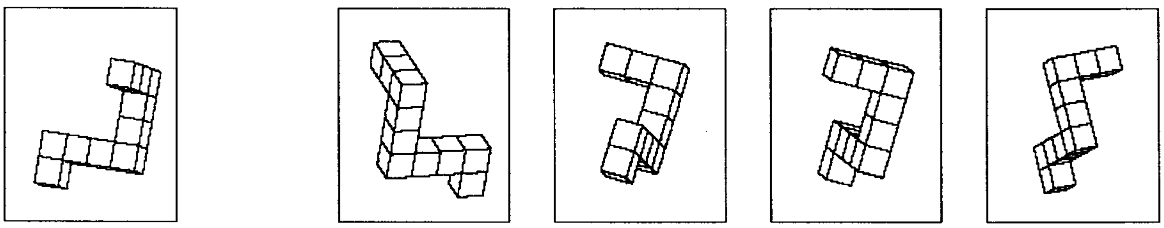
Zalevski, A., Meehan, J.W., & Hughes, P.K. (February, 2001). Size estimation with night vision goggles. *Air Operations Division: Aeronautical and Maritime Research Laboratory (DSTO-RR-0201).* Australia: Defense Science & Technology Organisation. Retrieved, September, 2004, from http://www.dsto.defence.gov.au/corporate/reports/DSTO-RR-0201.pdf.

# Appendix B

## Item 1 from the MRT(A).

Example question from the MRT(A)

| | |
|---|---|
| Look at this<br>this object: | Two of these four drawings show the same object.<br>Can you find those two? Put a big X across them. |



From Peters, et al. (1995). A redrawn Vandenberg and Kuse mental rotations test: Different versions and factors that affect performance. *Brain and Cognition, 28*, 39-58.

In each case, the stimulus target is on the left of the four sample stimuli. Participants had to determine which two of the four sample stimuli on the right of the target are rotated versions of the target stimulus. There are 24 items in the test each item has two and only two correct matches. A score of 1 is given if and only if both choices are correct. Thus, the maximum score is 24.

Appendix C

List of instructions for the JRD task and related Task Flow

*Instruction screen 1.* You will be asked to imagine you are facing a certain object in the environment. You will then be asked to indicate the direction to another object, relative to the one you are facing.

The questions will be presented on the screen and you will give your answer on the supplied answer sheets.

PRESS THE SPACEBAR TO CONTINUE READING THE INSTRUCTIONS

*Instruction screen 2.* The procedure will be as follows:

First focus on a fixation (+) point on the screen. Then a question will appear on the screen.

The question describes an object you are facing, and a second test object.

PRESS SPACEBAR TO CONTINUE READING THE INSTRUCTIONS

*Instruction screen 3.* You are to draw a line from the center of the circle on the answer sheet to the edge of the circle to indicate where you think the direction of the test object is relative to object you are facing.

The X on the top of the circle in which you record your answer will always indicate the direction you are facing.

The dot in the center of the circle represents your location, 1 meter away from the object you are facing.

PRESS SPACEBAR TO CONTINUE READING THE INSTRUCTIONS

*Instruction screen 4.* There are three examples on the first paper. Please carefully read those examples before continuing.

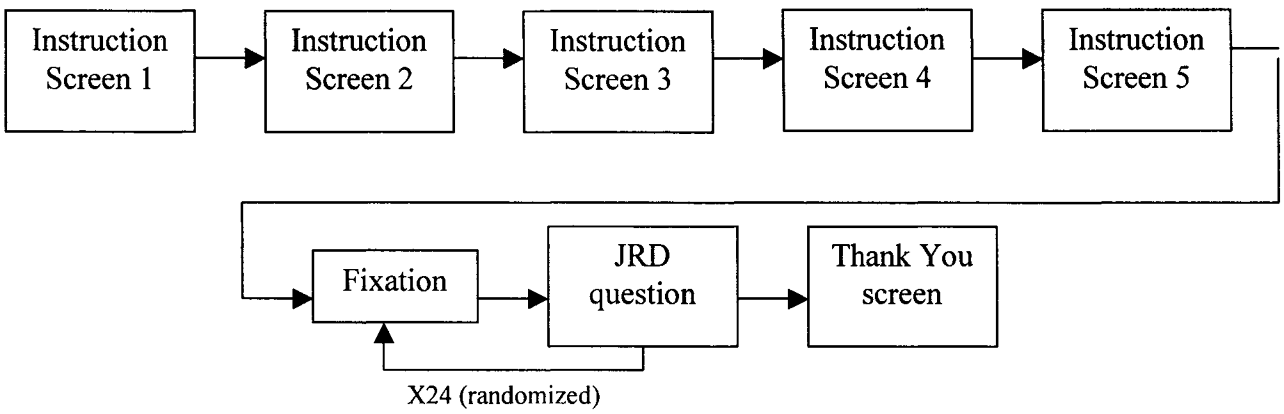
After you have understood the examples, press the SPACEBAR to continue with the instructions.

PRESS SPACEBAR TO CONTINUE READING THE INSTRUCTIONS

*Instruction screen 5.* Please answer as quickly and as accurately as you can.

Press the SPACEBAR to proceed to the first question. Always use the SPACEBAR to advance to the next question.

*Figure D1.* Task flow for JRD task.



Appendix D

List of questions for the JRD task according to object type and location proximity.

| Objects located within the same room |
|---|
| *Targeted objects*<br>1. You are standing facing directly in front of the ELECTRIC STAPLE GUN, 1 meter away. Please point in the direction of the PAINT ROLLER HANDLE.<br>2. You are standing facing directly in front of the TELEPHONE, 1 meter away. Please point in the direction of the STATUE OF THE CAT.<br>3. You are standing facing directly in front of the VIDEO TAPE, 1 meter away. Please point in the direction of the SKIS.<br>4. You are standing facing directly in front of the HANGING PAINTING OF THE TRUMPET, 1 meter away. Please point in the direction of the PROPANE TANK.<br><br>*Distracters*<br>5. You are standing facing directly in front of the MOP AND BUCKET, 1 meter away. Please point in the direction of the GARBAGE CAN.<br>6. You are standing facing directly in front of the SHOVEL, 1 meter away. Please point in the direction of the STACK OF WOODEN CRATES.<br>7. You are standing facing directly in front of the COAT, 1 meter away. Please point in the direction of the TIRE.<br><br>*A mix of targeted objects and distracters*<br>8. You are standing facing directly in front of the IRON, 1 meter away. Please point in the direction of the STATUE OF THE CAT.<br>9. You are standing facing directly in front of the BOTTLE OF BABY POWDER, 1 meter away. Please point in the direction of the SCISSORS.<br>10. You are standing facing directly in front of the PAINT ROLLER HANDLE, 1 meter away. Please point in the direction of the PAINT CANS. |
| **Objects located in separate rooms** |
| *Targeted objects*<br>11. You are standing facing directly in front of the COFFEE CAN, 1 meter away. Please point in the direction of the BOTTLE OF BABY POWDER.<br>12. You are standing facing directly in front of the TELEPHONE, 1 meter away. Please point in the direction of the SKIS.<br>13. You are standing facing directly in front of the TELEPHONE, 1 meter away. Please point in the direction of the ELECTRIC STAPLE GUN.<br><br>*Distracters*<br>14. You are standing facing directly in front of the TROPHY, 1 meter away. Please point in the direction of the DARTBOARD.<br>15. You are standing facing directly in front of the PAINT TRAY, 1 meter away. Please point in the direction of the TEA KETTLE.<br>16. You are standing facing directly in front of the TELEVISION, 1 meter away. Please point in the direction of the NEWSPAPER. |

17. You are standing facing directly in front of the TOOLCHEST, 1 meter away. Please point in the direction of the DUST BROOM.
18. You are standing facing directly in front of the TOOLCHEST, 1 meter away. Please point in the direction of the TEDDY BEAR.

*A mix of targeted objects and distracters*

19. You are standing facing directly in front of the TELEPHONE, 1 meter away. Please point in the direction of the PEPSI CAN.
20. You are standing facing directly in front of the MOP AND BUCKET, 1 meter away. Please point in the direction of the PROPANE TANK.
21. You are standing facing directly in front of the PAIR OF MITTENS, 1 meter away. Please point in the direction of the BASEBALL CAP.
22. You are standing facing directly in front of the SCISSORS, 1 meter away. Please point in the direction of the STATUE OF THE CAT.
23. You are standing facing directly in front of the BOTTLE OF BABY POWDER, 1 meter away. Please point in the direction of the LARGE PLANT.
24. You are standing facing directly in front of the HANGING PAINTING OF THE TRUMPET, 1 meter away. Please point in the direction of the DUST BROOM.

## Appendix E

### List of Instructions for the Distance Judgment Task and related Task Flow

*Instruction screen 1.* Your task is to judge which object, out of a choice of three objects, is closest in a straight-line distance to a test object (not necessarily walking distance).

There is only one correct answer.

You will first see a fixation (+) point, followed by a question.

Press the "a", "b", or "c" key for the correct answer.

PRESS THE SPACEBAR TO CONTINUE WITH THE INSTRUCTIONS

*Instruction screen 2.* Please answer as quickly and as accurately as possible.

You will have one practice question, followed by 24 of questions.

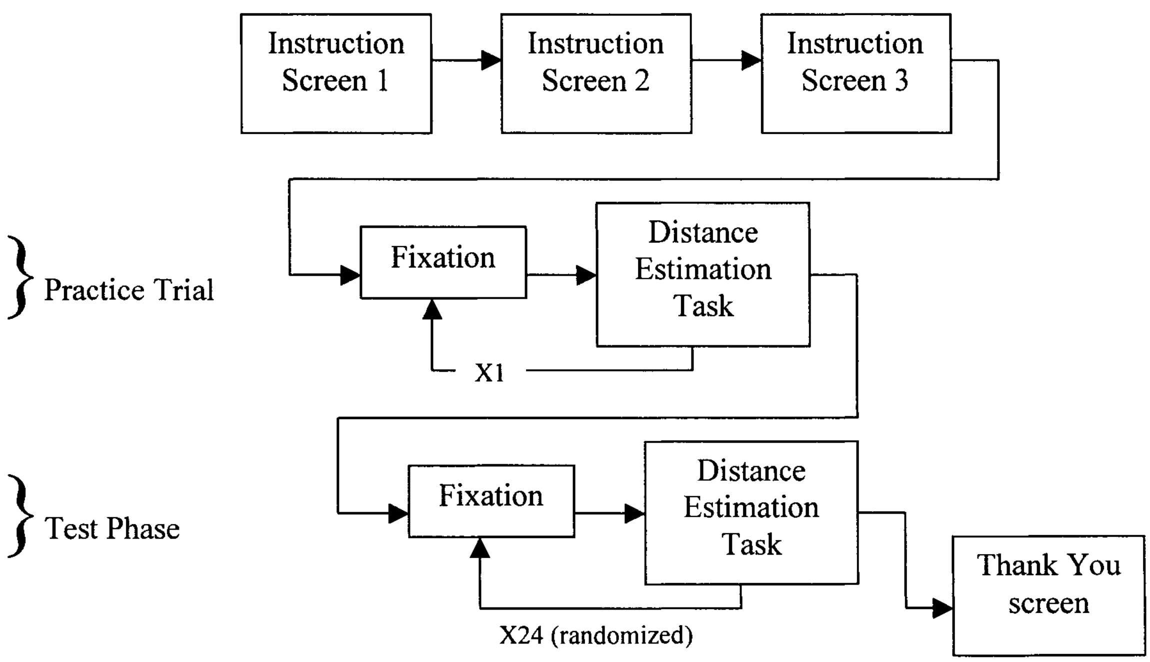
PRESS THE SPACEBAR TO BEGIN!

*Instruction screen 3.* After you have understood the examples, press the SPACEBAR to begin.

Ready?

PRESS SPACEBAR TO BEGIN!

*Figure E1.* Task flow for distance estimation task.



## Appendix F

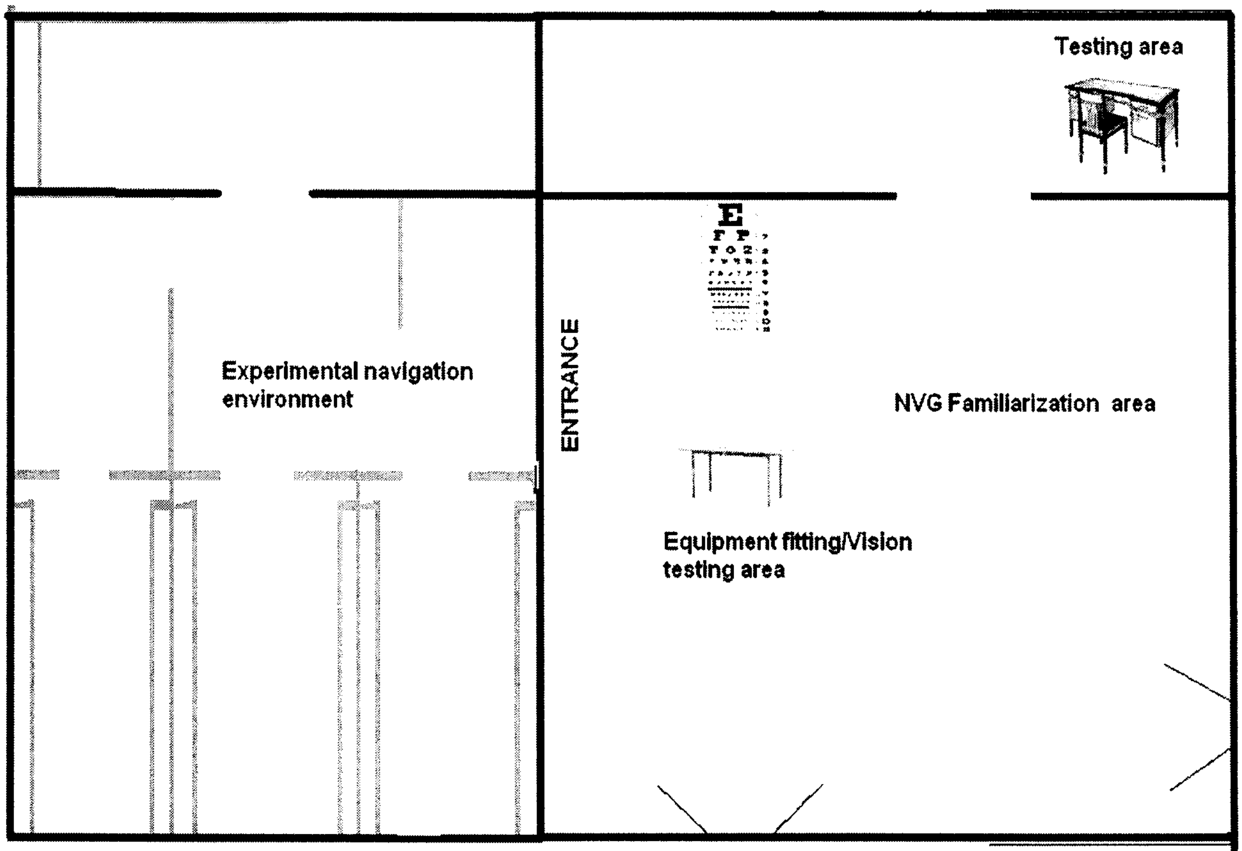
List of questions for the distance judgment task according to object type.

| | | | |
|---|---|---|---|
| ***Searched targets*** | | | |
| Test object: TELEPHONE | a. Skis | b. Propane tank | c. Coffee can |
| Test object: TELEPHONE | a. Propane tank | b. Bottle of baby powder | c. Hanging painting of the trumpet |
| Test object: VIDEO TAPE | a. Skis | b. Statue of the cat | c. Electric staple gun |
| Test object: HANGING PAINTING OF THE TRUMPET | a. Video tape | b. Bottle of baby powder | c. SKIS |
| Test object: COFFEE CAN | a. skis | b. Telephone | c. Bottle of baby powder |
| Test object: STATUE OF THE CAT | a. Paint roller handle | b. Coffee can | c. Propane Tank |
| Test object: ELECTRIC STAPLE GUN | a. Bottle of baby powder | b. Statue of the cat | c. Coffee can |
| **Non-searched targets** | | | |
| Test object: BASEBALL GLOVE | a. Paint cans | b. Large plant | c. Toolchest |
| Test object: TROPHY | a. Large plant | b. Television | c. Iron |
| Test object: TEA KETTLE | a. Fire extinguisher | b. Garbage can | c. Stack of wooden crates |
| Test object: IRONING BOARD | a. Newspaper | b. Shovel | c. Garbage can |
| Test object: COAT | a. Large plant | b. Shovel | c. Tea kettle |
| Test object: TOOLCHEST | a. Television | b. Large plant | c. Crib |
| Test object: TOOLCHEST | a. Trophy | b. Teddy bear | c. Bicycle |
| Test object: TOOLCHEST | a. Large plant | b. Crib | c. Television |
| **Mixed search and non-searched targets** | | | |
| Test object: SHOVEL | a. Pepsi can | b. Paint cans | c. Statue of the cat |
| Test object: BOTTLE OF BABY POWDER | a. Paint tray | b. Fire extinguisher | c. Skis |
| Test object: LARGE FAN | a. Paint tray | b. Hanging painting of the trumpet | c. Propane Tank |
| Test object: PAINT ROLLER HANDLE | a. Teddy bear | b. Tea kettle | c. Fire extinguisher |
| Test object: STACK OF WOODEN CRATES | a. Fire extinguisher | b. Video tape | c. Tire |
| Test object: SKIS | a. Coffee can | b. Plant | c. Teddy bear |
| Test object: SKIS | a. Statue of the cat | b. Propane tank | c. Dust Broom |
| Test object: BOTTLE OF BABY POWDER | a. Tire | b. Fire extinguisher | c. Shovel |
| Test object: MOP AND BUCKET | a. Large plant | b. Electric staple gun | c. Bicycle |

Appendix G

Layout of storage facility at the Flight Research Laboratory (FRL)

*Figure G1.* Three main areas of the storage facility at FRL are presented: testing area, equipment fitting/vision testing area and the experimental navigation environment.



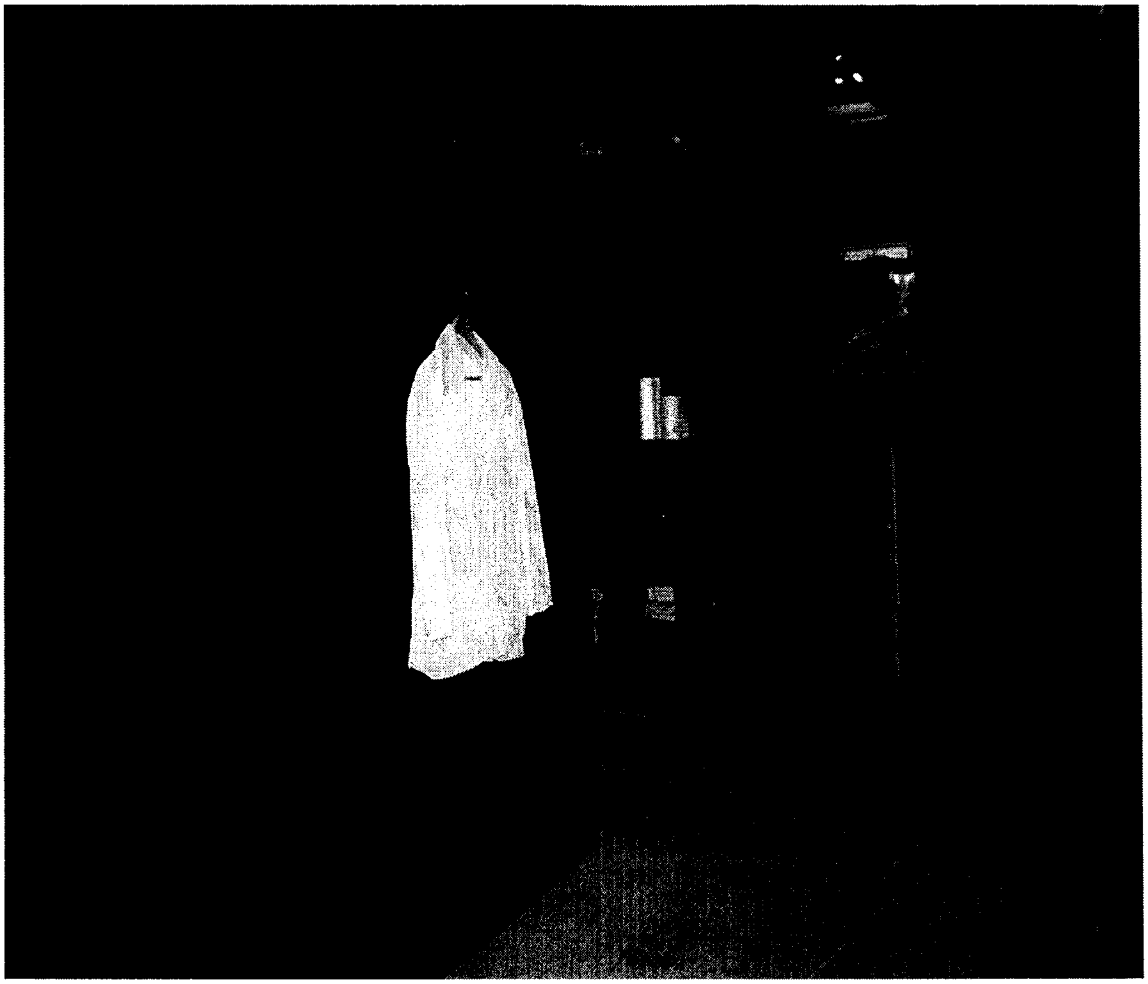
Appendix H

Picture of chin-rest and NVG-mount setup

# Appendix I

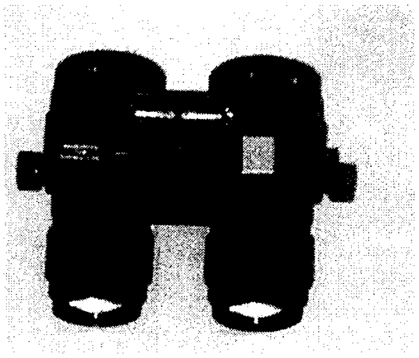
Picture of the hallway in the experimental navigation area

*Figure H1.* The existing wire-mesh dividers were covered with a fire resistant black material. Shown are the coat (distracter) and a hanging painting of a trumpet (target oject). Between the two objects is the opening to room B.



Appendix J

Typical F4949 set of ANVIS-9 NVGs



# Appendix K

## Illustrations of the head-mount NVG setup

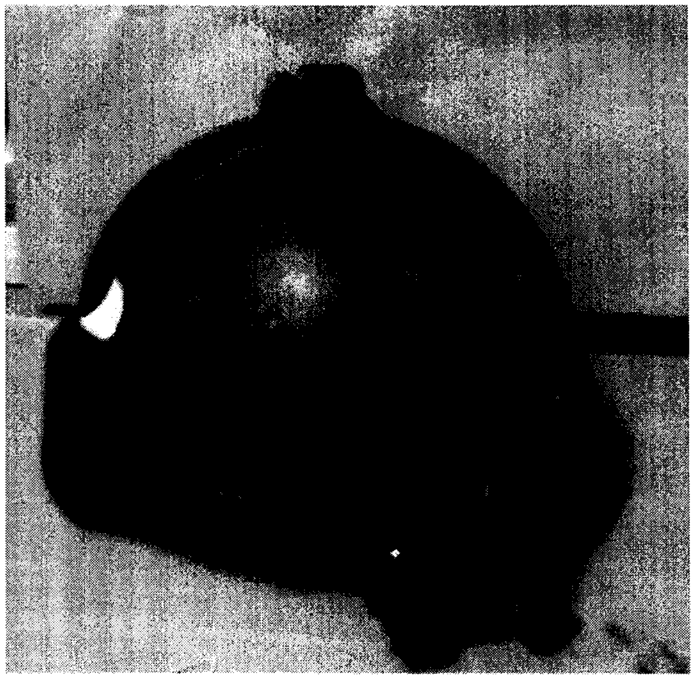


*Figure J1.* First, participants are fitted with a helmet (as the one seen above) and accompanying head-mount.

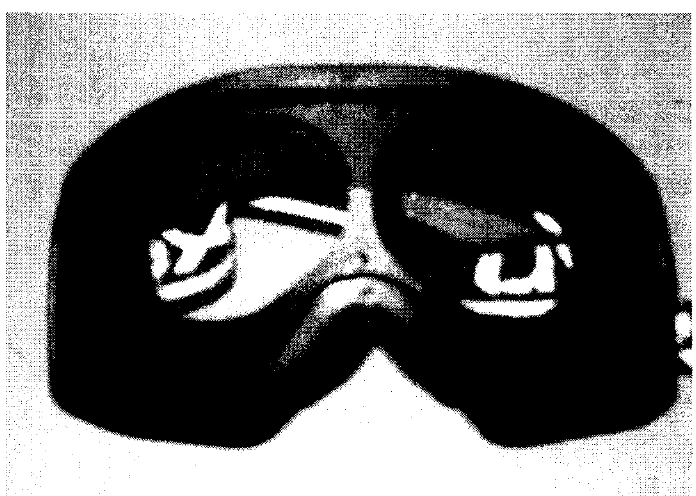


*Figure J2.* Next, these specially devised ski goggles are fit over the eyes to partly block participants' peripheral vision.

*Figure J3.* Then, this specially devised mask was put over the NVGs and fastened to the goggles and the helmet with velcro.

*Figure J4.* Picture of a participant with the head-mount NVG-setup

Appendix L

Standard stimuli used for testing visual acuity with NVGs.

*Figure M1.* USAF 1951 tri-bar resolution chart. From Pinkus, A. & Task, L. (1998). Measuring observer's visual acuity through night vision goggles. *SAFE Symposium Proceedings 1998, 36th Annual Symposium,* 1-11. Retrieved January, 2005, from www.hec.afrl.af.mil/Publications/ VisAcu.pdf.

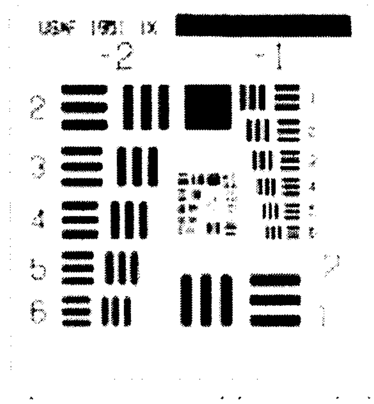



*Figure M2.* Standard horizontal and vertical gratings.

Breaks in NVG condition: Those wearing NVGs in the navigation task will receive breaks every 10-15 minutes on average. Further, the experimenter who will be monitoring you throughout the experiment will ensure that you are not suffering any discomfort. You can quit the study at any time.

Locale: The experiments will take place at the Flight Research Laboratory, Building U69, Uplands, Ottawa, ON, K1A OR6.

Potential Risk or Discomfort: There are no known risks or harms associated with this study. Your performance will not reflect any other higher-level cognitive ability (e.g. intelligence etc.). The only requirement for participation in this study is that you possess normal or corrected-to-normal healthy vision and that you have no experience using NVG technology. There are no direct benefits of this study, however, you will benefit indirectly by learning more about NVG function and spatial navigation tasks.

Confidentiality: All the information collected in this experiment will be kept confidential and will be identified by numbered coding only. It is important to emphasize that the data collected herein DO NOT reflect personal skill or sensitive information of any sort. The data cannot be used to derive sensitive personal information. If the results of the study are published, your name will not be used, and information disclosing your identity will not be released or published without your specific consent. All data will be maintained in a secure location at the Flight Research Laboratory and Carleton University. Only the lead investigators as listed above shall have direct access to these data.

Right to Withdraw: Participation in this study is wholly voluntary and you may refuse to participate, refuse to answer any questions or withdraw from the study at any time without incurring any penalty.

By signing this consent form, you are not waiving your legal rights.

**I have read the letter of information and I have had the nature of the study explained to me. All my questions have been answered to my satisfaction. I have had sufficient time to consider whether to participate in this study. I understand that my participation in this study is entirely voluntary and that I may withdraw from the study at any time without penalty. I voluntarily consent to participate in the study "Impact of Night Vision Goggles on Spatial Navigation and Cognition Task Performance".**

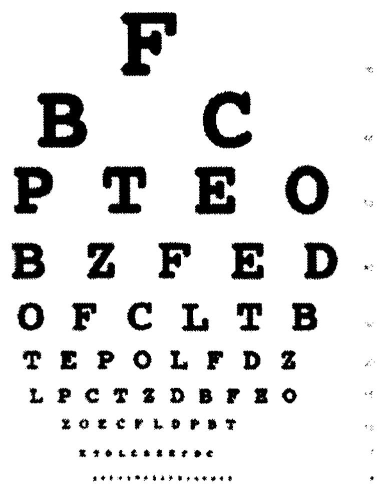
| | |
|---|---|
| Participant Name: | |
| Participant Signature: | |

To the best of my knowledge, the information in this consent form, and the information that I have provided in the response to any questions, fairly represents the project. I am committed to conducting this study in compliance with all the ethical standards that apply to projects that involve human subjects. I will ensure that the subject receives a copy of this consent form.

| | |
|---|---|
| Researcher Name: | Michelle Gauthier |
| Researcher Signature and Date: | |

Appendix N

Standard Snellen Eye chart for testing visual acuity



# Appendix O

## List of instructions for the search and wayfinding task

"Your job now is to search and locate various objects within this environment. I will first put this blindfold over your eyes/turn off the goggles to keep you from being able to see. I will bring you to a starting location within the environment, facing a certain heading. I will then instruct you to locate a certain object within this maze. You will then repeat that object and give me a verbal description of what it looks like. If you need any clarification on what it looks like, please ask. Once the blindfold is lifted from your eyes/the goggles are turned on, you will then be required to search and locate that particular object. You need to try and locate this object as quickly as possible, but while walking at a normal pace. Do not run. Also, take what you think is the best possible route to reach this object. I will follow behind you. Once you have located the object, walk directly to the object, face it, point to it, then call out "object found". I will then verify that it is the correct object.

I will then ask you to rate between 0 to 100 the extent of effort you needed to invest in order to perform the task (0=no effort, 100=extreme effort).

I will then blindfold you again/turn goggles off and bring you to the next starting location. That will be the end of one search and locate task. There will be 12 tasks in all."

Do you have any questions regarding this task? Ok, ready?

Appendix Q

Details of spatial ability on time to target analysis in the search and wayfinding task

Spatial ability was found to be a marginally significant covariate and was thus included in the model, $F(1,49) = 3.176$, $p<.081$. The assumption of homogeneity of regression slopes was then tested by a multivariate test to examine if there was an interaction between the covariate (spatial ability) and group (NVG vs control condition) factors. This test is to indicate if spatial ability had a parallel effect on each of the two groups. When an interaction effect is present, the impact of one variable depends on the level of the other variable and the interaction between the two variables represents the combined effects of two forces (i.e. the covariate and the treatment condition) in the data not just one (i.e., only treatment condition). As a result, the interpretation of main effects (in this case, of NVGs) with interactions present (between the covariate and the treatment) is likely to be misleading (Pedhazur and Schmelkin, 1991). An analytical approach other than an ANCOVA, such as the Johnson-Neyman Procedure, would have to be used to properly investigate the main effects (Pedhazur and Schmelkin, 1991). The results of this test failed to reveal a covariate-by-group interaction ($F<1$) and confirmed that an ANCOVA was an appropriate analysis for this data.

# Appendix R

## Details of spatial ability on orientation deviation analysis in the JRD task

To investigate whether MRT is an appropriate covariate, a 2 (NVG and Non–NVG) x 2 (Within same and in separate room) x (3) (Type of object) ANCOVA with MRT as the covariate was performed. This analysis revealed that spatial ability was found to be a marginally significant covariate and was thus be included in the model, $F(1,43) = 3.034$, $p<.089$. A multivariate test of homogeneity of regression slopes failed to reveal an MRT-by-group interaction ($F<1$) and confirmed that the ANCOVA is an appropriate analysis for this data.