Abstract Although Night Vision Goggles (NVGs) support and enhance visual perception in low-light or dark conditions the optical and electro-optical characteristics of NVGs impact visual perception differently than normal light conditions. Consequently, most published studies investigating the impact of NVG use on human performance have been based on psychophysical and perception research approaches [e.g., Macuda et al. (Proceedings of the Society of Photo-optical Instrumentation Engineers (SPIE) 5442:36–44, 2004); Niall et al. (Human Factors 41(3):495–506, 1999)]. However, anecdotal reports have suggested that NVGs affect spatial orientation and way-finding, implying that NVG use also influences human cognitive functions. Few studies have systematically characterized the cognitive nature of using NVGs, particularly on spatial behavior.

This paper aims to present an empirical methodology to study NVG use on way-finding and orientation performance, by introducing a spatial cognition research paradigm. The paradigm is a between subjects design composed of two main phases (1) a learning and practice phase; and (2) tests of acquired spatial knowledge. In the learning and practice phase, participants learn the environment through active navigation and way-finding, searching for targets within a life-sized maze with or without NVGs. In the second phase, knowledge of the environment is tested with two spatial memory tests (a judgment of relative direction and map drawing task). It is proposed that such an approach can be used to study both the perceptual and cognitive aspects of using head mounted vision enhancing devices, particularly for search and way-finding tasks. Furthermore, this approach can be utilized in the comparative and acceptance testing of new vision enhancing technologies. The methodology used in this study can also be utilized in developing and assessing training guidelines and strategies that are more compatible with humans’ spatial cognition processes. Some practical implications regarding NVG training and
possible field research to explore improvements in the design and deployment of vision-enhancing devices are also discussed.

In the current study, findings show that participants using NVGs while navigating and way-finding had longer navigation times and more excess turns compared to those not using NVGs. Moreover, a significant decrease in navigation times and navigational steps compared to controls. In the judgement of relative direction task, relative direction pointing to searched objects across rooms and to distractors in the same room was more accurate for those who performed the search without NVGs. In the map drawing task, participants using NVGs were more likely to position more objects incorrectly and receive worst map goodness scores. The results demonstrate that NVGs affect spatial navigation and way-finding performance and the acquisition of spatial knowledge. By objectively characterizing the impact of NVGs on spatial way-finding and orientation, the current results provide empirical evidence beyond that of anecdotal reports. The findings empirically demonstrate the effectiveness of the research paradigm.


Un paradigme de la recherche en cognition spatiale est présenté pour étudier l’influence exercée par le port de LVN. Ce paradigme est fondé sur deux étapes principales : 1) l’apprentissage et l’exécution d’exercices et 2) l’évaluation des connaissances spatiales acquises. À la première étape, les participants ont découvert un environnement par la navigation et le repérage actifs, en recherchant des cibles à l’intérieur d’un labyrinthe grandeur nature avec et sans LVN. À la seconde étape, la connaissance de l’environnement a été évaluée au moyen de deux tests de mémoire spatiale. Les résultats ont indiqué que la navigation et le repérage semblaient être plus difficiles avec des LVN (groupe expérimental), les temps de navigation étant plus longs et les virages inutiles étant plus nombreux comparativement à l’exécution de ces mêmes tâches sans LVN (groupe témoin). De plus, au cours d’essais de repérage menés avec le groupe expérimental, on a observé une diminution considérable et rapide des temps de navigation et une réduction des étapes de navigation par comparaison avec le groupe témoin. Dans une tâche d’appréciation de l’orientation relative, le positionnement relatif à des objets recherchés et à des
distracteurs se trouvant dans une même pièce était plus juste avec le groupe qui n’utilisait pas de LVG. Dans une tâche de dessin de carte, les membres du groupe portant des LVN avaient plus tendance à positionner incorrectement des objets et ont obtenu les pires résultats.

Ces résultats démontrent clairement que les LVN influent sur la performance en navigation spatiale et en repérage ainsi que sur l’acquisition de connaissances spatiales. En caractérisant objectivement l’influence des LVN sur le repérage et l’orientation spatiale, les résultats actuels fournissent une preuve empirique qui vient s’ajouter aux signalements anecdotiques. De plus, ces résultats peuvent constituer une démonstration empirique de l’efficacité de ce paradigme. Il est proposé d’utiliser ce type de méthode pour étudier les aspects perceptuels et cognitifs inhérents à l’utilisation de dispositifs d’amélioration de la vision portés sur la tête, en particulier dans des tâches de recherche et de repérage. En outre, cette méthode peut être utilisée pour l’essai comparatif et l’essai de réception des nouvelles technologies d’amélioration de la vision. Enfin, la méthode employée dans cette étude peut servir à l’élaboration et à l’évaluation de lignes directrices et de stratégies en matière de formation, en accord avec les processus de cognition spatiale humaine. Certaines répercussions d’ordre pratique, intéressant la formation sur l’utilisation des LVN et la recherche éventuelle sur le terrain, sont examinées, et ce, afin d’explorer les améliorations possibles sur le plan de la conception et de l’utilisation de ces dispositifs.

Most published studies investigating the impact of NVG on human performance have been based on psychophysical and perception research approaches (e.g., Macuda et al. 2004; Niall et al. 1999). These approaches have greatly enhanced our understanding of the impact of NVGs on performance of visual tasks. While NVGs support and enhance visual perception in low-light or dark conditions, these studies have shown decrements in visual performance when using NVGs.

NVGs are electro-optical devices that enhance visibility in low light. 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 perception, distance estimation to light sources and targets, and colour perception (Macuda et al. 2004; Niall et al. 1999). In addition, optical characteristics of NVGs such as the limited (40°) Field-Of-View (FOV) contribute to a number of problems which include an increased need for head movements (Geri et al. 2002). 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.

Anecdotal reports have suggested that NVGs affect spatial orientation and way-finding, implying that NVG also influences human cognitive functions. Despite the paucity of empirical investigations on NVGs and spatial cognition, some evidence suggest that NVG impact on visual perception also influences spatial perception and navigation performance (e.g., McLean et al. 1997; Geri et al. 2002; Macuda et al. 2004). Indeed, studies have shown that the visual limitations due to NVGs can...
result in increased spatial disorientation, poorer way-finding performance, and can increase workload (Braithwaite et al. 1998; McLean et al. 1997; Salazar et al. 2003). However, few studies have systematically characterized the cognitive nature of using NVGs, particularly with spatial performance.

This paper presents a spatial cognition research paradigm to study the impacts of NVG, in general, and the impact on spatial performance in particular. The research approach is based on two main phases (1) learning and practice; and (2) tests of acquired spatial knowledge. The approach applied in the current study is based on well established methodologies used in spatial cognition paradigms (Goldin and Thorndyke 1982; McNamara 1986; Bigelow 1996; Klatzky 1998). In the learning and practice phase, participants learn the environment, with or without NVGs, while searching for targets within a life-sized maze. In the second phase, acquired spatial knowledge is tested with two spatial memory tests. This paper demonstrates the efficacy of the paradigm by presenting an experiment done with it, along with some critique and lessons learned.

9.1 Method

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

1. NVG experimental group: Participants used NVGs in a target search and way-finding task.
2. Non-NVGs control group: Participants performed a target search and way-finding task without NVGs.

Materials and apparatus. The test environment was a 36 × 28 ft maze constructed from wood dividers covered with a black cloth. Prominent, highly visual, and salient landmarks (i.e., garbage can, broom, plant) were placed at various locations in the maze. Some of these landmark objects were used as the search targets. Placement of the objects created “fuzzy themes” in each room including a baby room, utilities room, sports room, kitchen and hallway area (Fig. 9.1).

Participants in the NVG group were fitted with a pair of ANVIS9 (Aviator Night Vision Imaging System), F4949 set of NVGs for the target search and way-finding task. For safety reasons, the experiment was conducted in lighting conditions. The amount of light entering the NVGs was reduced with a pinhole cover that was placed in front of the NVG objective lenses which also modified the focal length of the NVG system. This also allowed items close to the observer to be perceived (e.g. 6 in. to 20 ft.). The resulting light level that the participant saw in the NVG imagery was consistent with half-moon illumination conditions (RCA 1974). The resulting field of view (FOV) was nominally set to 30°. Since the experimental environment was lit, peripheral vision was blocked with a mask that fit over the face and goggles. NVGs were mounted on a Canadian issued military helmet and secured with a NVG head-mount. Participants from the control group were also required to wear
9 A Spatial Cognition Paradigm to Assess the Impact of Night Vision Goggles

the helmet during the target search and way-finding task to control for the possible influence of wearing a helmet.

### 9.2 Experimental Tasks

**Learning phase: Target search and way-finding task.** Participants searched for various objects within a life-size maze, with or without NVGs. There were 12 search trials designed to start at different locations in the maze and with headings of every 30° such as 0, 30, 60, 90, and so on. The mean number of minimal turns (3.5) and distance traveled (33 m) were counter-balanced across the 12 search trials. The trials were then randomized within and across participants.

**Spatial knowledge phase: spatial tasks.** Following the learning phase, three spatial memory tests were administered to assess the acquisition and accuracy of spatial knowledge.

1. **Judgment of relative direction (JRD) task.** Participants were asked to draw on a circle the direction of a given test object relative to an imagined position within the maze (e.g., “Imagine you are facing the bicycle, standing one meter away. Point in the direction of the skis.”). Participants were instructed to draw a line from the dot in the center of the circle 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 Fig. 9.2).

2. **Distance judgment task.** Adopted from Bigelow (1996), this task asked participants to determine, from memory, which one of three objects within the experimental environment was closest, in a straight-line distance, to a specified object (Fig. 9.3).
3. **Map drawing.** Participants were asked to draw, from memory, a map of the environment they learned including everything they could remember and label all objects and features.

### 9.3 Procedure

Participants received a general description of the experiment and its objective and were then randomly assigned to one of the two between-participant experimental conditions. Participants were tested individually. First, they performed the Peters
et al. (1995) Mental rotations test (MRT) – A to assess their spatial abilities. Participants’ visual acuity was then measured using the Snellen acuity test. Participants in the NVG group were then fully briefed on adjustment and focusing procedures in an interactive session with the experimenter and spent approximately 5–10 min adjusting and focusing their goggles. Acuity measurements taken following the adjustment and focusing procedures were nominally in the range of 20–30 to 20–40, which is the typical range of acuity values with NVGs. Participants in the NVG group were then given 5 min to walk around wearing the NVGs to become familiar with the visual distortions that NVGs can produce.

Participants were then led into the maze to a pre-defined starting location and heading to begin the first trial. At the beginning of each trial, participants in the control group were blindfolded while participants in the NVG group had the NVGs turned off. While still blinded, participants were instructed to find a given target within the maze. The participant began looking for the target when the experimenter said “Begin” following the removal of the blindfold or the NVGs turned on. Once the participant had located the target, they were required to face the target perpendicularly, point to it, and announce, “Object found”. 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 NVG group) and the participant was then taken to a new starting location, facing at another 30° heading and given the next task and so on. Once the 12 search/way-finding trials were completed, participants moved out of the maze and did three spatial memory tasks to assess their level of survey knowledge.

9.4 Measurements

9.4.1 Navigation Performance

Navigation performance measurements included the following:

1. **Time to target.** From the time that the blindfold was taken off of the participant in the control group or NVGs turned on until the participant announced “object found”.

2. **Number of excess turns (relative to optimal route).** The difference between the route taken by the participant and the shortest possible route (the minimum number of turns the participant needed to take to locate the object from starting location).

9.4.2 Spatial Knowledge Assessment

*Orientation deviation*: The absolute deviation, in degrees between 0° and 180°, between the correct directions of the test object and the direction drawn by the participant.
Distance judgment. The correct response for judging target-to-target distance. 

Map drawing. Due to the subjective nature of sketched maps, the data acquired in this study were used as a qualitative assessment of the participants’ cognitive maps. The following two measurements were used to assess the quality of participants’ drawn maps:

1. **Proportion of correct object placement.** The ratio of number of correctly placed objects drawn on the map and the total number of objects drawn on the map.
2. **Map goodness scores.** Adapted from Billinghurst and Weghorst (1995), goodness was rated on a scale of 1–5 by three raters who were familiar with the experimental environment but unaware of the participant’s identity and group affiliation. The raters were told to rate how useful the maps would be as a navigational tool in the maze. They were told to ignore the participants’ drawing ability and to focus on how well the map represented the experimental environment and the locations of the objects.

9.5 Results

9.5.1 The Learning Phase: Impact of NVGs on Navigation and Way-Finding Performance

To analyze the performance of search and way-finding with and without NVGs, the 12 search trials were divided into four blocks, each consisting of three trials. Analyses of the means of actual time to target and the number of excess navigational turns were performed for each of the blocks. Results showed that all participants, with and without NVGs, became quicker and more accurate in carrying out the search and way-finding task over the course of the experiment. These results simply reflected the practice effect. However, participants using NVGs while navigating and way-finding had longer navigation times and more excess turns compared to those not using NVGs. Also, over the course of the experiment, there was an earlier decrease in time to target with NVGs. Finally, there was a significant decrease in excess turns when using the NVGs compared to the control group. Taken together, the differences in performance during the search and way-finding task may reflect the level of acquired spatial knowledge, particularly survey knowledge, which was tested later.

9.5.2 Tests of Acquired Spatial Knowledge: Level and Accuracy of Survey Knowledge

**JRD task.** The judgment of relative direction 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 in both groups tended, in the judgment of relative direction tasks, to point closer to the correct direction of objects that were search targets in the navigation task 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 search targets, as opposed to implicit learning of objects that were distracters. This general finding varied as a function of using NVGs and room location. The control group did better than the NVG group in judging the relative direction between targets compared to distracters, in relative pointing to searched objects across rooms, and to distracters in the same room as compared with the NVG group.

**Distance judgement task.** The distance judgement task required participants to indicate, from memory, which one of three objects within the experimental environment was closest, in a straight-line distance, to a specified object. The results indicated that there were no differences between the NVG group and the control group. Accuracy scores were on average around 50%.

**Map drawing task.** The map task required the participant to draw a map, from memory, of the environment they learned in the learning phase. While the overall map drawings were surprisingly accurate, participants who wore NVGs during the search and way-finding phase were more likely to position objects incorrectly and to receive worse scores for map goodness compared to participants who did not wear NVGs.

### 9.6 Discussion

The findings demonstrate the efficacy of the spatial cognition research paradigm in assessing the impact of NVGs on performance, particularly spatial cognition and wayfinding. By objectively characterizing the impact of NVGs on spatial wayfinding and orientation, the results provide well-controlled empirical evidence beyond that of anecdotal reports. The following section describes how the methodology used in this study can be used to study both the perceptual and cognitive aspects of using head-mounted vision enhancing devices, particularly for search and way-finding tasks. This is followed by a discussion on how this methodology can be applied to possible field research to explore improvements in the design and deployment of vision-enhancing devices and for practical implications regarding NVG training. Finally, a critique of the applied methodology is discussed. A theoretical discussion of the findings is presented in Gauthier et al. (2008).

#### 9.6.1 Implications for NVG Design and Procurement

One benefit of the spatial cognition paradigm is its efficacy and high ecological validity. Most tasks performed with NVG and other vision-enhancing HMDs are spatial, and this paradigm assesses them directly and realistically. Consequently, aspects of the performance data collection and the proposed performance metrics
can be standardized and applied in making design, acceptance, and procurement
decisions. This paradigm can be used for comparative studies, where comparisons
can be relative to established and substantiated benchmarks or relative to other
equivalent devices. NVGs with different fields of view, including panoramic NVGs,
provide an example.

Another approach is to use the paradigm in virtual worlds where the direction of
simulating vision-enhancing devices would be investigated by adjusting various
parameters (e.g., FOV, depth of field, acuity levels) to examine their impact on spatial
cognition. Design improvements can then be recommended based on acceptance.

9.6.2 Implications for Training

Simply practicing with NVGs results in improved way-finding performance, and
contemporary training programs are based on this principle. However, the implica-
tions of using NVGs on spatial cognition suggest that training guidelines and strate-
gies should be modified so that they are more compatible with human spatial
cognition. Training programs can be modified to increase and maintain spatial naviga-
tion and orientation. A way to implement this strategy would be to develop a
simulated navigation and way-finding training task with “pop quizzes” to frequently
test NVG users’ spatial knowledge (see Parush et al. 2007; Blades et al. 2002). For
instance, certain spatial tasks, such as relative pointing, verbalization or modeling
(map drawing) could be performed during a search and locate task or free active
exploration. NVG users should be exposed to as many different viewpoints as pos-
sible. The impact of NVGs on the acquisition of spatial cognition could then be
assessed at different times throughout the training session. And finally, formative
feedback could then be given to correct any likely inconsistencies in their spatial
performance and memory. Feedback techniques have been successful in training
NVG users to estimate distances. For instance, there was a significant improvement
in distance estimates when observers had previous knowledge of the distances
involved and feedback of their performance during a training session. Niall et al.
(1999) confirmed the value of direct verbal feedback for distance estimation with
NVGs. They showed that observers typically underestimated the true physical dis-
tance only if they had limited experience using NVGs and had no feedback on their
performance.

The present methodology can also be used in developing, comparing, and
assessing different training strategies with the use of vision-enhancing devices. For
instance, this approach can assess and develop different training strategies on way-
finding and orientation performance to compensate for a narrow FOV. The impact
of different training strategies on positional awareness, head movements and scan-
ning can be investigated. Another promising avenue is comparing simulation-based
training (e.g., simulating wayfinding with NVGs on a computer screen) and the
transfer of learning to NVGs in the field. Several studies have found that simulated-based
training has positive transfer training effects to real world tasks (Witmer et al. 1996;
Loftin and Kenney 1995). In the simulated approach, a simulated image from a visual database is generated and displayed on a high-quality graphics workstation displaying a virtual environment on a standard computer monitor, on a head-mounted display or on a large front-mounted projection screen. If the image is to follow the observer’s line of sight, a head-tracking system that updates the display in response to natural head movements is included. Visual effects, including NVG-specific effects such as FOV, monochrome vision, scintillating noise, etc could be manipulated. In the stimulation approach, imagery would be provided that is visually and spectrally correct to stimulate the actual NVGs worn by an observer. The experience should be similar to or nearly identical to viewing the real world scene with NVGs under realistic night conditions.

9.6.3 Critique and Lessons Learned

While the advantages of using the spatial cognition paradigm are straightforward, there are several limitations to this approach that should be developed and addressed.

*Navigation task.* The 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. What is the optimal performance level of NVGs without training and can we reach asymptotic levels with additional training? Many studies have assessed performance on spatial tasks longitudinally (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 with not having NVGs. Future studies could address this question by assessing how long it takes participants to learn a simulated/stimulated or real operational environment, determined by the number of trials needed to master spatial tasks (i.e., no error rates in navigation and/or orientation performance). The impact of NVGs on the acquisition of spatial knowledge could then be assessed at different times throughout the study.

*Distance estimation task.* There were no significant differences between the NVG and control group in the distance estimation task. Indeed, the results indicated that participants’ responses were barely above chance. 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 and Hayes-Roth 1982; Bigelow 1996) is indicative of survey knowledge. Increased experience with an environment leads to improved performance on distance estimation tasks, indicating greater survey knowledge (Thorndyke and Hayes-Roth 1982; Bigelow 1996). The distance
estimation task used here 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. 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. The poor performance in this study is probably not due to lack of survey knowledge but how this task was assigned. In Bigelow (1996), participants had no time limit to make distance estimation judgments. In the current study, participants had a time limit of 15 s to make their distance judgments. This task required participants to recall four 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. Anecdotal reports from participants following this task were that many of their answers were guesses. Pilot tests of this task were done as a paper and pencil test with unlimited time, and judgments were quite accurate. In summary, while distance estimation tasks appear to be a reliable measure of survey knowledge, the methods used in this study need to be explored further.

**Expert vs. novice users.** The results of this study should be interpreted with caution when generalizing to experienced NVG users. Walking in normal visual conditions usually requires little attention: it is “automatic” (Montello 2005). 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 2005). The application of these strategies, when they are first learned and applied, requires attentional resources (Montello 2005). With increased practice, tasks become more automatic, requiring fewer attentional resources. It has been reliably shown that navigation performance improves with increased practice with the environment and the task (Blades et al. 2002; Gillner and Mallot 1998; Parush and Berman 2004; Parush et al. 2007). In the present investigation NVG users quickly learned to navigate with NVGs, and became more efficient. Increased practice with NVGs resulted in a reduced demand for explicit strategies. Experienced NVG users would already have had plenty of practice with NVG, potentially leaving many attentional resources towards the search and wayfinding task. NVG experts are usually trained navigators – which could affect navigation and wayfinding.

**Map drawing task: missing objects.** In the map drawing task, only the location of correct object placement was measured. The emphasis of the map drawing task was to assess the effect of NVGs on participants’ accuracy of the spatial location of objects and not object memory. Therefore the number of missing objects in participants’ maps was not assessed. The number of missing objects could have shown the level of spatial knowledge acquired during the learning phase. And finally, attentional resources and operator confidence may have been two other factors involved in group differences in performance. Future studies should investigate the possible influence of attentional resources and operator confidence on spatial cognition.

The spatial cognition paradigm used in this study can serve as a basic experimental paradigm in testing the development or acceptance of these new technologies. Our interest is to further training methodologies and to develop technology.