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Contributions to the Development of VE-Assisted Training of Spatial Behavior

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14. ABSTRACT

An initial three-part effort aimed at integrating spatial cognition research with virtual environment technology resulted in (a) a conceptual framework for classifying spatial abilities into three "families" (object identification, wayfinding & orientation, and target acquisition/avoidance); (b) results from an experimental study showing that global and local-object frames of reference are optimal for communicating direction of movement in fixed-observer situation; and (c) results from an experimental study showing that distance estimation skill could be trained using visual feedback and transfered to novel settings. Follow-up work focused on training estimation of distance and direction. A series of experimental studies showed that skill in estimating perceived and traversed distance can be trained using digital photographs and that this skill is transferable to novel settings. These findings support the use of VE-based techniques for training fundamental spatial skills relevant to military applications.

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Contributions to the Development of VE-Assisted Training of Spatial Behavior

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Summary

"Contributions to the Development of VE-Assisted Training of Spatial Behavior" was a two-year grant-funded effort focused on laying the groundwork for integrating contemporary research on spatial cognition with emerging virtual environments (VE) technology. Initially, effort was distributed among three activities with the following results:

- A conceptual framework was developed for the classification of functional spatial abilities. According to this framework, the most common spatial abilities for military applications can be considered as three functional "families" of abilities. The first of these involves object identification, the second involves wayfinding and orientation skills, and the third involves target acquisition/intercept avoidance.

- An experimental investigation of the use of different spatial frames of reference (FOR's) in identifying direction of movement from a fixed-observer perspective was conducted. Results indicated that global and fixed-object FOR's were optimal under fixed-observer conditions. Additionally, it was found that switching between different FOR's did not generally result in errors or delayed direction identification.

- An experimental investigation of the training and transfer of distance estimation skill was conducted. Results indicated that visual feedback was an effective means of training skill in estimating perceived distance, and that skill acquired in this manner readily transferred to a novel setting.

Follow-up effort was concentrated exclusively on experimental studies of the effectiveness of digital photographs in training distance and direction estimation skill. These investigations yielded the following results:

- Experimental studies showed that visual feedback using digital photographs was an effective means of training skill in estimating both perceived (fixed observer) and traversed (mobile observer) distance. Skill acquired in this manner readily transferred to a novel setting.

- Experimental studies show that visual feedback using digital photographs was not effective in training skill in estimating perceived (fixed observer) direction because error was low prior to training.

Overall, the findings of the project lay the groundwork for significant additional work integrating VE technologies into research on fundamental spatial skills relevant for military applications. Possibilities include a comprehensive VE-based assessment scheme and various VE-based training technologies for spatial cognition and behavior.

Table of Contents

1. Introduction

1.1 Overview

"Contributions to the Development of VE-Assisted Training of Spatial Behavior" was a two-year ONR-funded research project with the following objectives: (1) conduct a conceptual analysis supporting the development of a battery of essential spatial skills for wayfinding, orientation, and cognitive mapping; (2) design, conduct, and evaluate an empirical study focusing on observer's ability to use and switch between different spatial frames of reference; and (3) design, conduct, and evaluate a series of empirical studies focusing on the training and transfer of distance and direction estimation skills. The initial two objectives were met in the first year of the project, during which time an initial study of distance estimation training was also conducted. The research described in this report covers the third objective, which involved a series of three experimental studies. The first study was concerned with the estimation of perceived distance, the second with the estimation of perceived direction, and third with the estimation of traversed distance. The central issue in each study was the extent to which skill acquired through feedback in one setting could be transferred to a different setting.

These studies were conducted to support the effort of the Office of Naval Research (ONR) to develop virtual environment (VE) technology for assessment and training of spatial skills. At the high end of the dimension of cost and technical sophistication, VE technology is being dedicated to the recreation of the experiences provided by specific vehicles and specific environments to provide simulations of specific combat and combat-support skills (e.g., ship handling, assault team coordination). At the low end of the dimension of cost and technical sophistication, VE technology is being used in the recreation of generic operational environments to study, assess, and train general spatial skills (e.g., distance estimation, map reading). The research in this project falls under the latter rubric.

1.2 Background

ONR is among a number of research-dedicated organizations exploring the application of VE technology for assessing, training, and maintaining skilled spatial behavior. As Schmorrow (2000) pointed out, a wide variety of crucial activities (expeditionary warfare in urban settings; reconnaissance; artillery and surface fire support, close air support, and piloting) involve spatial and navigational skills. VE technology is a substantial source of untapped potential that could be applied to assessing and training these skills (see Durlach et al., 1999).

Results from a variety of studies have indicated that spatial information about large-scale environments can be acquired effectively through experience in VE's (Darken & Sibert, 1996; Jacobs, Laurance, & Thomas, 1997; Ruddle, Payne, & Jones, 1997; Richardson, Montello, & Hegarty, 1999; Waller, 2000), and that the abilities supporting this learning are similar to those involved in environmental learning under natural circumstances (Richardson et al., 1999; Waller, 2000). Furthermore, these is evidence of transfer of knowledge from VE-based training to real-world circumstances (Bliss, Tidwell, & Guess, 1998; Waller, Hunt, & Knapp, 1998; Witmer, Bailer, Knerr & Parsons, 1996). However, there remains a need for basic research on component skills reflected in tasks used in studies such as these. A better understanding of these component skills can result in a valid baseline against which the utility of VE-based training can be assessed. In addition, insight into component skills can provide a clearer picture of the VE to real-world transfer of acquired capability and of the spatial knowledge that is expressed in terms of these components. For example, knowledge of a route is often assessed by analyzing distance estimates (see Allen, Siegel, & Rosinski, 1978), and survey knowledge can be assessed by analyzing a set of distance and direction estimates from multiple positions (Kirasic, Allen, & Siegel, 1984; Waller, 1999). In these procedures, estimation skill is confounded with environmental knowledge. In other words, distance and direction estimates reflect not only the individual's knowledge of where objects and event are located but also his or her facility with the estimation process.

In general, researchers assume roughly equivalent estimation skill across groups of participants, and in most instances, this assumption is defensible and of little scientific or practical importance. Similarly, in many studies estimates are made on a relative or proportional basis, and skill in using specific standard units (for example, estimating distance in meters and direction in degrees) is not necessary. But in many real-world tasks, particularly those in military settings, metric accuracy can be vitally important. Errors of a few meters of a few degrees could have significant consequences for task performance and, by extension, to operational success. Thus, it is important to consider distance and direction estimation skill to be important skills at face value as well as embedded components in a variety of other tasks.

The ability to estimate distance and direction to target objects with accuracy and reliability is a useful skill in a variety of military situations, and accordingly the psychological processes underlying distance and direction estimation are a logical focus of pragmatically oriented basic research. Distance and direction estimates are a common means of verbally conveying information about the location of environmental objects and events both in relation to each other and in relation to an observer's point of view. Thus, such estimates are frequently taken in research tasks and in everyday situations as direct manifestations of an individual's knowledge of a specific environmental layout. Skill in estimating distance and direction are quite reasonably a central consideration in research aimed at evaluating difference means of providing individuals with information about a novel environmental setting or in training them to perform tasks in such settings.

The research in this project was concerned with training and transfer of skill in estimating distances in meters and directions in degrees. Despite a sizeable literature on these and related topics, it is difficult to locate studies that are concerned specifically with this topic. How accurate are individuals in estimating distances to targets in meters and directions in degrees without training? If estimation skill improves with feedback, how quickly does it improve? Does estimation skill acquired in one environmental setting transfer to another setting? Can skill in estimating distance and direction be acquired using pictures of environmental layouts? If it can, does the skill transfer to real-world environments? These questions were addressed in three experimental studies.

1.2.1 *Distance Estimation.* Two classes of situations involving the estimation of distance are of interest in terms of training and transfer of skill. One class involves the estimation of distance to target objects or locations visible from a specific viewpoint; the other class involves the estimation of traversed distance.

A series of elegant studies by Gibson and her colleagues demonstrated that skill in estimating distance, expressed in standard units, to target objects visible from a specific viewpoint can be trained vry rapidly using simple feedback or knowledge of results (Gibson & Bergman, 1954; Gibson, Bergman, & Purdy, 1955). Furthermore, Gibson and her colleagues concluded that training of this type did not involve perceptual learning per se in the sense that feedback did not lead to grater sensitivity to distance defining information in the optic array provided by the environment. Instead, increased accuracy in estimating distance was the result of a cognitive process of calibration, which involved relating the information in the optic array to a mode of symbolic expression based on distance units of equal length. Once the calibration was achieved, it was applicable in different settings. Previous work in this project substantiates the effectiveness of feedback in training distance estimation skill and the transfer of skill from one field setting to another (Allen, 2000).

A critically important issue with respect to the use of VE-based training of spatial skill is whether distance estimation skill trained in VE can be transferred to field settings. In this regard, the results of a distance estimation study by Fine and Kobrick (1983) are of considerable concern. After analyzing distance estimates made to objects in the field and those made to objects photographed in the same settings, these investigators found that although average estimated distances were very similar under the two circumstances, the participants in the study could easily be divided into two groups. One group performed more accurately in the field than when responded to photographs; the other group performed more accurately when responding to photographs than when estimating distance in the field. Based on their results, Fine and Kobrick (1983) recommended against using photographs to train distance estimation skills for military applications such as forward observers for field artillery units. These findings raise a number of important questions including the influence of initial training, the effects of terrain, and the effects of distance range on the accuracy and reliability of distance estimates. Nevertheless, the most pressing issue for investigation remains the use of photographs for training distance estimation skills.

Most of the studies involving estimation of traversed distance have focused on the biasing effects of environmental features such as landmarks and route segments (see Montello, 1997). Generally, traversed distance can be estimated with considerable accuracy up to a limit (around 25 m or so) on the basis of a single glance from a designated viewpoint (Loomis, DaSilva, Philbeck, & Fukusima, 1996; Thomson, 1983). However, estimates of traversed distance in meters along routes that lead through areas that cannot be viewed simultaneously are typically characterized by substantial error and large inter-individual variability (for example, see Allen, Kirasic, Dobson, Long, & Beck, 1996). Although training studies are rare, it is clear from studies of the acquisition of orienteering skill that calibration of traversed distance is enhanced through practice with feedback (see Bina, 1986; Omodei, McClennan, & Whitford, 1998). One of the purposes of this project was to bolster this conclusion with a straightforward experimental study focusing on training and transfer.

It is interesting to note that a great deal is known about the estimation of traversed distance as depicted in pictorialized routes. Most relevant to the topic of VE-based training are the findings that individuals obtain relatively accurate distance knowledge form a series of slides and from videotaped routes, with little difference between these two presentation formats (Allen et al., 1978; Cornell & Hay, 1984); the accuracy of distance knowledge increases with repeated viewing of the route (Allen et al., 1978); and distance knowledge is acquired more rapidly by actually traveling the route than by viewing a pictorial depiction of it (Cornell & Hay, 1984; Gale, Golledge, Pellegrino, & Doherty, 1990). Given the typical increase in accuracy and decrease in variability of distance estimates along pictorially presented route that results from repeated viewing, it is not too surprising that positive transfer of route knowledge from VE-based presentation to a corresponding real-world situation has been reported (Witmer et al., 1994). Nevertheless, it has not yet been demonstrated that skill in estimating traversed distance can be transferred from pictorial training to real-world environments. Such a demonstration, which would bolster the case for VE-based assessment and training of fundamental spatial skills, was one of the objectives of this project.

1.2.2 *Direction estimation.* Many studies have used the accuracy of participants' pointing to places out of sight as an index of their knowledge of objects' locations in large-scale environments (for example, Allen et al., 1996; Kirasic et al., 1984; Richardson et al., 1999; Waller, 2000). However, there are no comparable studies in which direction estimates in standard units (i.e., bearing expressed in degrees) have been used as an expression of direction knowledge. Unpublished studies by the principle investigator for this project have shown that the ability to pivot and walk directly to a target object over a short distance (five meters) is very accurate. Accordingly, it may be proposed that , just as in the case of distance, skill in expressing direction in terms of degrees may be trained rapidly with feedback, verbal or visual, and may transfer readily. Testing this proposal was an objective of this project.

1.3 Related Work Completed in Year 01

One of the three strands research proposed in the first year of this project was an empirical study focusing on the training and transfer of skill in estimating distances up to 300 meters from a designated viewpoint. The purpose of the study was to replicate the finding of Gibson et al. (1954, 1955) that training based on simple feedback would result in considerable accuracy in estimation performance achieved in a brief period of time and that this skill would be readily transferred to distances estimated from novel viewpoints. An important addition was a comparison of different means of providing feedback. The effectiveness of verbal feedback was compared to the effectiveness of visual feedback of the type that might be used in VE-based displays.

In the experiment, all participants estimated distance to targets in a real-world field setting. Three conditions were compared, with three phases in the procedure for each condition. In the first phase, participants in all conditions estimated a set of distances without feedback. In the control condition, participants in the second phase estimated another set of distances, with no feedback or strategy provided. In the verbal feedback condition, participants in the second phase received verbal feedback after each estimate; the feedback consisted of the correct metric distance expressed in meters. In the visual feedback condition, participants received visual feedback after each estimate in the second set in the form of red traffic cones placed at 50 meter intervals immediately before and after the target distance. In the third phase of the procedure, all participants were tested by providing a new set of estimates in a novel field setting, with no feedback given.

The results of this study indicated that both verbal and visual training were effective in enhancing distance estimation skill. The estimates of participants in the control condition produced distance estimates that were grossly inaccurate, particularly to far targets (over 100 meters), and their performance did not improve as a function of simply repeatedly making estimates in the absence of feedback. In the initial set of estimates that involved no feedback, the participants who would later receive verbal or visual feedback were also inaccurate in their estimates. However, their performance improved dramatically in both feedback conditions so that minimal error was evident at the end of the brief training exercise. Distance estimates produced in the novel field setting indicated that the skill resulting from feedback transferred to a new viewpoint and a novel third set of novel distances. Both verbal and visual feedback produced excellent distance estimation performance, and neither of these means of providing knowledge of results was more effective than the other.

These results confirmed that skill in producing estimates of absolute distance in standard units can be trained quickly and that this skill is transferable to similar field settings. The finding that visual feedback in the form of equal-interval markers placed in the environment led to transferable skill leads to optimism concerning the prospects of VE-based methods of training skilled spatial behavior.

2. Experimental Study of the Estimation of Perceived Distance

2.1 Purpose

This study was designed to show the relative effectiveness of training individuals to estimate perceived distance in meters using digital photographs. Specifically, the efficacy of training using digital photographs was compared to that of training using verbal feedback and visual feedback in the field. This comparison involved data collected in year 01 of this project.

2.2 Method

2.2.1 *Participants.* Data were collected from 64 participants between the ages of 17 and 25 years of age. All participants were right-handed and had 20/40 vision or better. Corrective lenses were permitted. Participants were assigned to the following five conditions: Control with Viewing Experience in the Field (3 men, 13 women), Direct Verbal Feedback in the Field (3 men, 9 women), Indirect Visual Feedback in the Field (2 men, 11 women), Control with Pictorial Viewing Experience (3 men, 9 women), and Indirect Visual Feedback through Pictorial Viewing Experience (3 men, 8 women).

2.2.2 *Materials and Experimental Setting.* The experiment took place in two large adjacent fields used as parking lots. One field served as the training setting; the other served as the transfer of training setting. In the training setting, two sets of distance estimation trials were prepared prior to data collection. Each set consisted of 10 distinct standpoints, each associated with a particular target location. The target distances ranged from 30 to 300 meters in 30 meter intervals. Exact distance included a randomly generated number from one to nine either added or subtracted from the interval. Thus, the first set of trials involved targets 28, 61, 92, 127, 141, 173, 212, 239, 265, and 305 meters from the designated standpoints; the second set involved targets 35, 56, 88, 114, 153, 175, 204, 249, 262, and 293 meters from the designated standpoints. In the transfer test setting, one set of distance estimation trials was prepared, with each trial involving a different standpoint and target distance. This set involved targets 32, 67, 82, 123, 144, 189, 201, 239, 264, and 291 meters from the designated standpoints. For all estimation trials, an octagon-shaped stop sign 0.7 meters wide served as the target.

Direct verbal feedback in the field involved informing participants of the exact distance to target expressed in meters. Indirect visual feedback in the field involved participants seeing the target with visual milestones at the two nearest 50-meter intervals from the standpoint that preceded the target and followed the target. For example, if the target was 173 meters from the standpoint, visual milestones were placed at 100 meters, 150 meters, 200 meters, and 250 meters from the standpoint. Indirect visual feedback through pictorial viewing experience involved the same technique as that used with indirect visual feedback in the field except that the second set of distances with visual feedback was provided by means of a pictorial presentation on a laptop computer. As with the field group, these participants view targets, made estimates, and then received feedback in the form of the same scene with labeled distance markers inserted. The control group for this training technique also produced their second set of distance estimates to targets shown on the laptop computer, but no scenes with feedback markers were provided.

2.2.3 *Procedure*. Participants were tested in groups of from four to eight individuals. Transportation was provided from the university campus to the field settings where data were collected. After being briefed with regard to the purpose of the study, participants provided the first set of distance estimates. During the procedure, one experimenter escorted participants to each standpoint in success and instructed them to face in a particular direction, which was always away from the location of the target on the trial that immediately followed. A second experimenter fixed the corresponding target for each trial in succession. When the target location had been fixed for a particular trial, the first experimenter instructed the participants to turn, ref to a meter stick on the ground, and estimate distance in meters to the target location by writing down their estimates. Estimates were collected after each trial so that prior estimates were not available to participants on subsequent trials.

All participants completed the first set of estimates without feedback. Experience during the second set varied according to experimental condition. Participants in the Direct Verbal Feedback in the Field condition were told after each trial the exact distance in meters to the target, those in the Indirect Visual Feedback in the Field condition viewed the visual milestones placed before and after the target location, and those in the Control with Viewing Experience in the Field condition received no information about the accuracy of their estimates. Participants in the Indirect Visual Feedback with Pictorial Viewing Experience condition were escorted to a viewing station arranged in the back of a minivan in the field site, where they estimated distances and then received visual feedback in the form of the same scene with labeled visual markers appearing an regular intervals before and after the target location. Participants in the Control with Pictorial Viewing Experience condition were also escorted to the viewing station, where they estimated distances to a second set of targets. However, no feedback was provided.

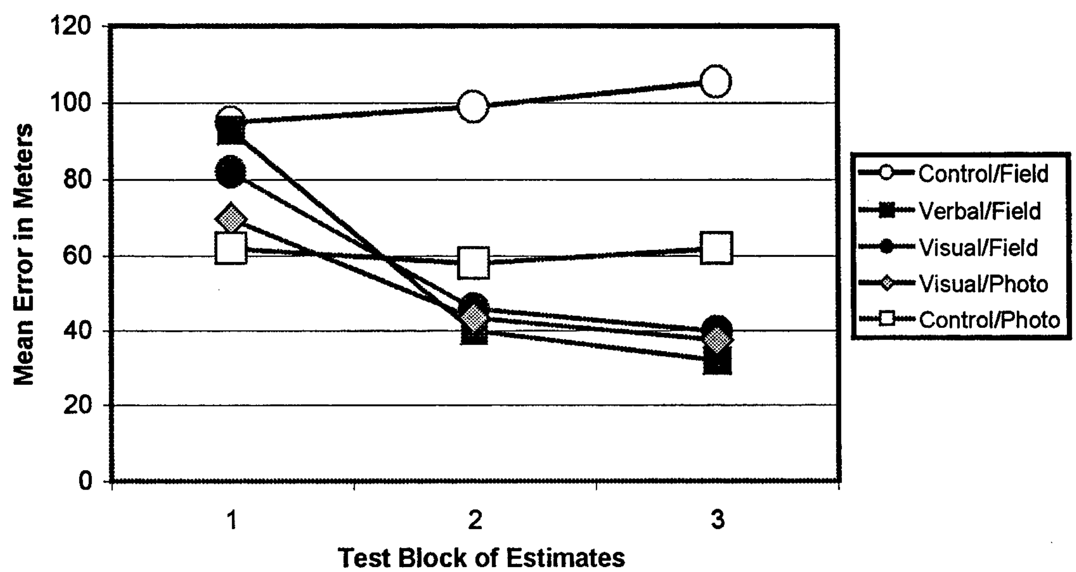
After the second set of estimates, the experimenters escorted the participants to the second field for a third set of distance estimation trials. None of the participants received feedback regarding the accuracy of their estimates during the third set. When the third set was competed, the participants were debriefed, thanked, and transported back to the university campus.

2.3 Results

The primary analysis for the distance estimation data was a 5 (condition) x 3 (target set) mixed analysis of variance (ANOVA) performed on the absolute error of estimates in meters. For this analysis, data from two participants were omitted as outlying data point that severely skewed the distribution of estimates in the first set. The results yielded significant main effects of condition and of target set, and a significant interaction between these factors. Mean distance estimation errors are shown in Figure 1. Post-hoc comparisons showed that mean error did not change across target sets for the

Control with Viewing Experience in the Field condition and for the Control with Pictorial Viewing Experience condition. In contrast, mean error was significantly reduced across target sets for the other three conditions. Additional post-hoc comparisons within the first test set showed that groups began the experiment with differing levels of distance estimation skills, with the greatest contrast being between the two control groups. Similar comparisons within the third test set showed that groups who had experienced training with feedback were more accurate that were the two control groups.

Figure 1. Mean Absolute Error in Estimating Perceived Distance



2.4 Discussion

The evidence shows that the various forms of feedback regarding distance to target were equally effective in training distance estimation skill and that such skill transferred to a new setting regardless of the circumstances under which it was acquired. Thus, direct verbal feedback regarding estimates to a viewed target, indirect visual feedback showing the target bracketed by labeled visual markers, and indirect visual feedback showing targets and visual markers in digital photographs all yielded comparable results in terms of improved accuracy. No such improvement resulted from simply viewing targets and estimating distances to them either in the field or in digital photographs. Also, the evidence showed that despite considerable group differences in distance estimation skill at the beginning of the experiment, skill levels were enhanced through training so that groups with feedback ended up superior to control groups, regardless of how well the control groups performed originally. Critically important for the potential application of VE technology were the findings that estimation skill acquired through the use of digital photographs was as robust and transferable as that acquired in the field.

3. Experimental Study of the Estimation of Traversed Distance

3.1 Purpose

This study was designed to show the relative effectiveness of training individuals to estimate traversed distance in meters using digital video presentations. Specifically, the efficacy of training using digital video presentations was compared to that of training using verbal feedback and visual feedback in the field.

3.2 Method

3.2.1 *Participants.* Data were collected from 85 participants between the ages of 17 and 25 years of age. All participants were right-handed and had 20/40 vision or better. Corrective lenses were permitted. Participants were assigned to the following five conditions: Control with Walking Experience in the Field (5 men, 15 women), Direct Verbal Feedback in the Field (6 men, 9 women), Indirect Visual Feedback in the Field (5 men, 10 women), Control with Video Viewing Experience (5 men, 15 women), and Indirect Visual Feedback through Video Viewing Experience (6 men, 9 women).

3.2.2 *Materials and Experimental Setting.* The experiment involved two routes, each near 1.5 km in length, near and within a university campus. One route served as the training setting; the other served as the transfer of training setting. In the training setting, two sets of distance estimation trials were prepared prior to data collection. Each set consisted of 10 distinct standpoints, each associated with a particular target location. The target distances ranged from 30 to 300 meters in 30-meter intervals. Exact distances were selected to match those in the experiment concerned with perceived distance. Thus, the first set of trials involved targets 28, 61, 92, 127, 141, 173, 212, 239, 265, and 305 meters from the designated standpoints; the second set involved targets 35, 56, 88, 114, 153, 175, 204, 249, 262, and 293 meters from the designated standpoints. In the transfer test setting, one set of distance estimation trials was prepared. This set involved targets 32, 67, 82, 123, 144, 189, 201, 239, 264, and 291 meters from the designated standpoints.

Direct verbal feedback in the field involved informing participants of the exact distance to target expressed in meters. Indirect visual feedback in the field involved participants seeing the target with visual milestones at the two nearest 50-meter intervals from the standpoint that preceded the target and followed the target. For example, if the target was 173 meters from the standpoint, visual milestones were placed at 100 meters, 150 meters, 200 meters, and 250 meters from the standpoint. Indirect visual feedback through video viewing experience involved the same technique as that used with indirect visual feedback in the field except that the second set of distances with visual feedback was provided by means of a video presentation using a microcomputer. As with the field group, these participants view targets, made estimates, and then received feedback in the form of the same scenes with labeled distance markers inserted. The control group for this training technique also produced their second set of distance estimates to targets shown on the computer screen, but no feedback markers were provided in the video.

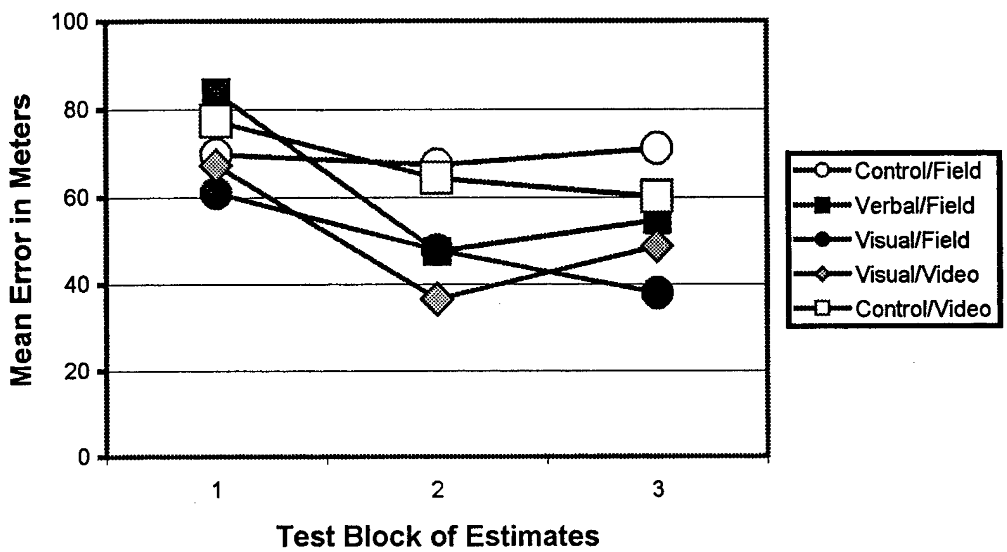
3.2.3 *Procedure.* Participants were tested in groups of from two to four individuals. The experimenter led the participants to the start of the first route near the university campus. After being briefed with regard to the purpose of the study, participants were led by the experimenter along the designated route. As they past a designated landmark, their attention was directed to it, and as they progressed from that landmark to the point from which distance to the landmark was to be estimated, they engaged in a task that disrupted the intentional counting of steps. When they arrived at a designated estimation point, each participant wrote down an estimate in meters to the target they had past along the route. A meter stick was placed on the ground as a referent. This procedure was repeated ten times, once for each target. Targets were not visible from estimation standpoints. Estimates were collected after each trial so that prior estimates were not available to participants on subsequent trials.

All participants completed the first set of estimates without feedback. Experience during the second set varied according to experimental condition. Participants in the Direct Verbal Feedback in the Field condition were told after each trial the exact distance in meters to the target, those in the Indirect Visual Feedback in the Field condition viewed the visual milestones placed before and after the target location, and those in the Control with Walking Experience in the Field condition received no information about the accuracy of their estimates. Participants in the Indirect Visual Feedback with Video Viewing Experience condition were escorted to a viewing station in a campus building, where they estimated distances along a new route, receiving visual feedback in the form of the same scene with labeled visual markers appearing an regular intervals before and after the target location. Participants in the Control with Video Viewing Experience condition were also escorted to the viewing station, where they estimated distances along a second route. However, no feedback was provided. After the second set of estimates, the experimenter escorted the participants along a second route and obtained a third set of distance estimates. None of the participants received feedback regarding the accuracy of their estimates during the third block of estimates. When the third set was competed, the participants were debriefed, thanked, and dismissed.

3.3 Results

The primary analysis for these data was a 5 (condition) x 3 (target set) mixed analysis of variance (ANOVA) performed on the absolute error of estimates in meters. The results yielded significant main effects of condition and of target set, and a significant interaction between these factors. Mean distance estimation errors are shown in Figure 2. Post-hoc comparisons showed that mean error did not change across target sets for the Control with Viewing Experience in the Field condition and for the Control with Video Viewing Experience condition. In contrast, mean error was significantly reduced across target sets for the other three conditions. Additional post-hoc comparisons within the first test set showed that groups began the experiment with differing levels of distance estimation skills, but the only two that differed significant were the two field groups with feedback. Comparisons within the third test block showed that groups who had experienced training with feedback did not differ from each other.

Figure 2. Mean Absolute Error in Estimating Traversed Distance



3.4 Discussion

The evidence shows that the various forms of feedback regarding distance to target were equally effective in training skill in estimating traversed distance. It also indicated that such skill transferred to a new setting regardless of the circumstances under which it was acquired. Thus, direct verbal feedback regarding estimates to targets along a route, indirect visual feedback showing the target bracketed by labeled visual markers, and indirect visual feedback showing targets and visual markers in digital photographs all yielded comparable results in terms of improved accuracy. No such improvement resulted from simply viewing targets and estimating distances to them either in the field or in digital photographs. Also, the evidence showed that despite considerable group differences in distance estimation skill at the beginning of the experiment, skill levels were enhanced through training so that groups with feedback ended up superior to control groups, regardless of how well the control groups performed originally. Critically important for the potential application of VE technology were the findings that estimation skill acquired through the use of digital photographs was as robust and transferable as that acquired in the field.

4. Experimental Study of the Estimation of Perceived Direction

4.1 Purpose

This study was designed to show the relative effectiveness of training individuals to estimate perceived distance in meters using digital photographic presentations.

4.2 Method

4.2.1 *Participants*. Data were collected from 26 participants between the ages of 17 and 25 years of age. All participants were right-handed and had 20/40 vision or better. Corrective lenses were permitted. Participants were assigned to the following five conditions: Control with Viewing Experience in the Field (3 men, 5 women), Direct Verbal Feedback in the Field (2 men, 7 women), and Indirect Visual Feedback in the Field (3 men, 6 women).

4.2.2 *Materials and Experimental Setting*. The experiment took place in two 10-meter in diameter circles on grass-covered surfaces on a university campus. One circle served as the training setting; the other served as the transfer of training setting. In the training setting, two sets of distance estimation trials were prepared prior to data collection. Each set consisted of 16distinct sighting orientations at a position in the middle of the circle, with each orientation associated with a particular target angle. The target angles were selected to cover the entire range from 0 to 360 degrees, with two targets in each quadrant. Target values can be described as being in the range 0 to 180 degrees to the left or the right (L or R) of the standing orientation. Exact angles were determined by generating random numbers within the quadrants, with the restriction that they be separated by at least 10 degrees. Thus, the first set of trials involved targets 10-L, 14-R, 40-R, 42-L, 50-L, 52-R, 78-L, 78-R, 112-l, 113-R, 122-R, 128-L, 140-R, 140-L, 161-R, and 167-L degrees off of the designated sighting orientation; the second set involved targets 14-R, 21-L, 31-R, 31-L, 60-L, 60-R, 70-L, 73-R, 96-R, 100-L, 123-L, 130-R, 148-L, 152-R, 160-L, and 171-R degrees off of the designated sighting orientation. In the transfer test setting, one set of direction estimation trials was prepared, with each trial involving a different standpoint and target direction. This set involved targets 8-L, 23-R, 37-L, 38-R, 54-L, 57-R, 70-L, 71-R, 110-R, 112-L, 127-L, 132-R, 147-R, 151-L, 160-R, 165-R degrees from the designated standing orientation. For all estimation trials, the center of an octagon-shaped stop sign 0.7 meters wide served as the target.

Direct verbal feedback in the field involved informing participants of the exact direction to target expressed in degrees left or right. Indirect visual feedback in the field involved participants seeing the target with visual milestones at the two nearest 10-degree intervals from the standpoint that preceded the target and followed the target. For example, if the target was 38 degrees to the right, labeled visual milestones were placed at 30 and 40 degrees to the right.

4.2.3 *Procedure*. Participants were tested individually. After being escorted to the site of the experiment and briefed with regard to its purpose, participants provided the first set of direction estimates. For each trial, the experimenter positioned the subject in a specific standing orientation and then fixed the corresponding target. When the target location had been fixed for a particular trial, the experimenter instructed the participant to turn his or her head to view the target while keeping feet fixed firmly in the original orientation. Then the subject returned to face straight ahead and wrote on a small piece of paper his or her direction estimate in degrees. The estimate was collected after each trial so that prior estimates were not available to participants on subsequent trials.

All participants completed the first set of estimates without feedback. Experience during the second set varied according to experimental condition. Participants in the Direct Verbal Feedback in the Field condition were told after each trial the exact direction in degrees to the target, those in the Indirect Visual Feedback in the Field condition viewed the visual milestones placed before and after the target angle, and those in the Control with Viewing Experience in the Field condition received no information about the accuracy of their estimates. After the second set of estimates, the experimenters escorted the participants to the second circle for a third set of direction estimation trials. None of the participants received feedback regarding the accuracy of their estimates during the third set. When the third set was competed, participants were debriefed, thanked, and dismissed.

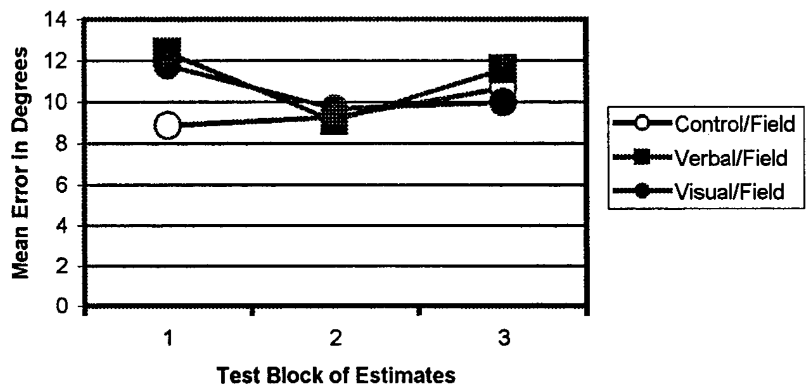
4.3 Results

The primary analysis for the distance estimation data was a 3 (condition) x 3 (target set) mixed analysis of variance (ANOVA) performed on the absolute error of estimates in degrees. The results yielded only a significant main effect of target set. Mean direction estimation errors are shown in Figure 3. Post-hoc comparisons showed that mean error decreased significantly from the first target set to the second but increased slightly from the second to the third so that the third differed from neither the first or the second sets. Although the interaction was not significant ($p = .06$), inspection of Figure 3 clearly shows that the control group did not fit this pattern, and instead showed no change across the sets.

4.4 Discussion

The evidence shows that distance estimation training had a small but significant impact, reducing average error by two to three degrees. However, this improvement in performance did not transfer significantly to another setting. Additional data collection is needed to show whether the apparent (but statistically insignificant) difference between training conditions is reliable. Figure 3 clearly suggests that the transfer effects of visual feedback in the field might be stronger than those of verbal feedback in the field. Without either replicating this pattern or adding to the present sample, however, the issue must remain unresolved.

Figure 3. Mean Absolute Error in Estimating Perceived Direction



5. Conclusions and Implications

5.1 Conclusions

- Skill in estimating perceived distance in meters, traversed distance in meters, and perceived direction in degrees can be trained rapidly by providing distance to target or angle to target as feedback.
- Feedback has the same beneficial effect on training distance estimation skill regardless of whether actual distance values are reported verbally in the test environment, inferred from visual milestones inserted into the test environment, or inferred from visual milestones inserted into digital photographs of the test environment.
- Distance estimation skill transfers from field to field and from digital photographs to field.
- Individuals vary in terms of their distance estimation skill prior to training.
- Regardless of distance estimation skill prior to training, improvement does not result from additional viewing experience or additional estimation experience without feedback.
- Skill in estimating perceived direction in degrees can be trained rapidly by providing angle to target as feedback.
- Feedback has the same beneficial effect on training direction estimation skill regardless of whether actual angle values are reported verbally in the test environment or they are inferred from visual milestones inserted into the test environment.
- There is no reliable evidence that direction estimation skill acquired through feedback transfers from field to field.

5.2 Implications

Skill in estimating perceived distances in meters up to 300 meters can be readily trained using feedback in the form of labeled visual markers inserted into digital photographs. Skill acquired in this manner transfers from the pictorial environment to new field environments. The basis for this skill and its transfer lies in the ability to impose a metric scale on perceived scenes, accommodating the compression of texture gradients in the optic array. Future research should focus on evaluating the effectiveness of training on the estimation of much longer distances (up to 1000 meters), and on determining the transferability of skill across radically different types of terrain.

Skill in estimating traversed distances in meters up to 300 meters can also be readily trained using feedback in the form of labeled visual markers inserted into digital videos depicting routes. Skill acquired in this manner transfers from the video route to new routes in the field. The basis for this skill and its transfer lies in the ability to impose a metric scale on rate of travel information contained in optical flow. Future research should focus on evaluating the effectiveness of training on the estimation of much longer distances, and on determining the transferability of skill across radically different types of terrain and different rates of movement depicted in video presentations.

Skill is estimating perceived direction can be readily increased using feedback in the form of labeled visual markers inserted into the field. The basis for this skill lies in the ability to partition the circular field surrounding an observer into equal units in reference to a standard (i.e., 180 degree half circle). Unfortunately, there was not unequivocal evidence that this improved skilled level transfers to a new field. Accordingly, no video-based skill training effort was undertaken in this study. Future research should focus on two issues. First, a replication of the test of transfer should be conducted using more statistical power. Second, there is a need for training when directions to distant, unseen targets are estimated. Under such circumstances, observers must rely on mental geometry in reference to observable landmarks (i.e., dead reckoning) to estimate directions.

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