# Effects of Augmented Reality Display Settings on Human Wayfinding Performance

Brian F. Goldiez, Ali M. Ahmad, and Peter A. Hancock

***Abstract*—Augmented reality (AR) entails overlaying the real world with information from computer-generated displays. Current AR technologies support limited mobility, although this is expected to change in the future. This paper presents experimental results of effects of various AR display strategies on human performance in a simulation-based analog of a "search and rescue" navigation task. The augmentation scheme was a spatially and temporally registered map that was overlaid onto a corresponding real-world maze. The experiment required the participants to traverse the maze, periodically answer orientation questions, obtain a target object, and exit the maze as quickly as possible. One hundred twenty participants were evaluated in six different conditions. There were two control conditions (paper map or compass prior to entering the maze), and four experimental conditions (combinations of egocentric and exocentric maps, and continuously on or on-demand map display). Performance measures consisted of duration of time to traverse the maze and percentage of maze covered. AR resulted in better performance than the control conditions in terms of accuracy by facilitating the participants' coverage of the maze. Results show that the better performance with respect to time was in the map control condition. This result may be due to the small size of the maze, which could be memorized. However, AR is expected to exhibit better performance compared to a paper map, when more complex environments are employed. These results demonstrate promising benefits in mobile AR usage in specific navigation tasks. Design guidelines were extracted to guide future AR systems continued progress in enhancing performance.**

***Index Terms*—Augmented reality, human performance, mobile computing, navigation wayfinding.**

## I. Introduction

Augmented reality (AR) entails overlaying the real world with information provided via some form of computer-generated display. When using AR, "A participant wears a see-through display (or views video of the real world with an opaque HMD) that allows graphics or text to be projected in the real world" [1]. The real world is therefore the baseline upon which information is added in contrast with virtual reality (VR), which completely immerses the human within a computer-generated environment. AR is characterized by three fundamental factors 1) real-time operation; 2) spatially and temporally registered data; and 3) interactivity [2].

AR has the potential to enhance human performance in the real world by adding pertinent information where and when it is needed. Information can be added in three primary ways. The first entails adding information that is not an integral part of the natural scene, as occurs, for example, with heads-up display in an aircraft. The second method adds information intended to be spatially fused, indistinguishable, and integral with the natural scene such as inserting a virtual building into a cityscape. The third method consists of portraying information that is already in the natural environment, but is not immediately viewable without augmentation. Computer-enhanced sensory fusion displays are prime examples of this latter approach. Each of these AR approaches offers different potential to enhance human performance in certain tasks.

Most existing AR research has focused on the technological aspects of creating and sustaining AR environments with very few studies on perceptual issues and, to our knowledge, none on cognitive aspects of AR [1]. Prototypical mobile AR systems are currently available, so research may now be conducted to assess the effects of various modes of untethered augmentation on human performance. This form of augmentation is expected to increase as the ubiquity of wireless computing and telephony rapidly permeate contemporary society.

One area of human performance that can now be studied in augmented reality is wayfinding. Wayfinding is characterized by acquiring landmarks, routes, and survey knowledge about an area [3]. Wayfinding is an area that can be difficult to train without using the real environment. For example, there are particular difficulties in acquiring wayfinding knowledge in virtual environments. Many of these difficulties are due to limited navigational metaphors in these environments [4].

Augmentation promises facilitation in improving wayfinding performance in many situations, where users are unfamiliar with a particular space, and may need external information to achieve an objective. For example, wayfinding is of contemporary interest for military, public safety agencies, travel industry, and the elderly. The availability of prototypical mobile AR systems now can support studies in wayfinding using various AR strategies.

Currently, our primary objective is to study the impact of different AR display configurations and information presentation techniques on wayfinding performance using mobile AR. Here, we evaluate a specific form of wayfinding; search and rescue. Search and rescue entails completely searching an area, finding an objective, and exiting the area by taking the shortest egress route learned during ingress. The entire area must be searched

Manuscript received April 27, 2005; revised November 2, 2005. This work was supported in part by the Office of Naval Research under Grant N00014-03-1-0677 and in part by the Army Research Office under Grant DAAD 19-01-1-0621. This paper was recommended by Associate Editor Y. Jin.

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Digital Object Identifier 10.1109/TSMCC.2007.900665

to identify all dangers in the space. It is important to minimize wayfinding time in order to maximize safety for self and the objective (often a person). Spatial recall of the area traversed is often a requirement in search and rescue navigation.

For the purpose of the current experiment, a mobile AR system was employed. This system, called the Battlefield Augmented Reality System (BARS), was developed by the Naval Research Laboratory (NRL) and provided for the present research by the U.S. Army Research Institute for Behavioral Sciences. BARS is a wearable computer system that supports a variety of tracking and display technologies. Currently, we know of no display devices in production that allow mobility and support the second method of augmentation (fusion) previously noted. Therefore, in the present experiment, the augmentation entailed information that was not part of the environment, i.e., a graphically displayed map of a maze.

## II. Synopsis of Literature

### A. Background Literature

AR can be considered as a component of a continuum of various types of available realities. To capture these respective differences, Milgram *et al.* describe a taxonomy that depicts the relationship between reality, virtual reality, and augmented reality. The spectrum is anchored on one end by reality, and the other end by virtual reality. They position augmented reality between the two [5].

Navigation capabilities have received considerable attention with respect to performance in virtual environments. Comparative performance has been explored when navigating in real and virtual environments [6]. However, an optimal approach to learning navigation using various forms of virtual reality has yet to emerge. Nevertheless, it is still useful to consider selective research in navigation in real and virtual environments for insights that might be useful in studying how AR might support improved performance in navigation.

In one study, a maze was created to explore spatial knowledge acquisition in virtual environments [7]. Upon traversing the maze, users selected among different maze representations to determine interface fidelity, or the difference between user's mental model and actual environment. The results showed that even relatively low fidelity virtual environments allow the creation of useful representations of large spaces; nevertheless, short exposures to the virtual environment were normally no better than using a map. The same strategy should be extendable to AR systems, when tasks are similar because the VR and AR share certain common technologies. However, it is understood that there can be differences in implementations of augmented and virtual realities because some systems, strategies, or studies might only be relevant to one or the other.

Regarding navigation, there are other insights from studies that can serve as a useful baseline to AR-oriented studies. For example, in one study it was determined that humans tend to create cognitive maps of areas based on how spatial information is obtained [8]. Using paper maps results in acquisition of an orientation specific perspective, but that limited view only has an effect if learning is involved, i.e., performance as measured by time to travel from a start to an end point was affected if the map was learned. Learning takes time and consumes memory resources, both of which may be limited in situations such as search and rescue or other tasks.

In another experiment, researchers studied the utility of different map configurations used by pilots when navigating [9], [10]. The results showed that there is a cost imposed on working memory, that is, task and map dependent. In particular, egocentric (the so-called forward or track up) maps can be disorienting if not properly configured, and when placed approximately in the participant's field of view. This result might be useful in virtual or augmented reality settings involving navigation.

The effect of north-up versus track-up map orientation (representing exocentric and egocentric views, respectively) in virtual environments was explored [12]. There was an alignment effect when using both types of map configurations. It was shown that acquisition of knowledge from physical exploration (primary learning) does not result in alignment effects. The experiments conducted in a stationary setting confirm the benefits of navigation to acquire multiple views of an environment.

In another study, navigation was tested in a virtual maze by seeing how participants found short cuts, estimated distances, and drew sketch maps after their traversal [11]. This study discussed mental representation of spaces via cognitive maps, and reported evidence that immersive virtual environments did not facilitate acquisition of survey knowledge.

Virtual reality systems support, but also exhibit difficulties with various aspects of navigation such as users becoming disoriented [13], [14]. There are particular difficulties in acquiring wayfinding knowledge in virtual environments [4]. Many of these difficulties are due to limited navigational metaphors in the virtual environment, and the difficulty in visualizing and creating the resulting mental models from distal orientation landmarks. It is therefore interesting to see how a mixture of real and virtual can be carefully integrated to facilitate wayfinding by retaining existing navigational metaphors, and adding additional cues through augmentation.

Careful comparison between the features and techniques of VR and AR systems and associated research provides some insights into designing effective AR systems for navigation and wayfinding. For example, use of strategically placed software labels for building markers were qualitatively shown to be beneficial in a navigational AR system [15]. This is an important technical support work, and gives an insight into usability and navigation using AR. However, there are no existing principled evaluations of utility or strategies for human navigation using mobile AR.

Regardless of the technical approach taken in AR, it is important to consider the symbiosis between the user and the equipment. People and machines interact in a variety of ways. It is important that these interactions be supportive of task performance. It is particularly important to understand how machines and people interact, when machines are worn by people or in close proximity [16]. AR is a technology that can influence these aforementioned interactions. For more extensive review of the state-of-the-art, see [17].

Fig. 1. Battlefield augmented realty system (BARS) used in the present study, front and side view.

### B. Research Hypotheses

From the foregoing discussion of the present state of understanding, two obvious questions emerged, which we have formed into distinct hypotheses:

*Hypothesis 1:* Search and rescue wayfinding using a real-time AR map display will improve performance in terms of the participant's speed and accuracy of maze traversal compared to the nonaugmented control conditions.

*Hypothesis 2:* Within AR conditions, the use of an "on-demand" map display will reduce time, and improve accuracy on the primary wayfinding task as compared to a continuously on map display.

## III. Experimental Method

A series of experiments were conducted. The first was intended to ensure that the testing methods and data collection techniques were sound, as well as to assess whether any procedural changes were needed. Analysis of these pilot data produced slight changes in the experimental design. The next two experiments had the same basic format. A total of 120 participants with mean age of 26.5 years and standard deviation of 9.9 years were tested. The participants were divided equally between the treatment conditions, and the treatments were balanced across gender.

### A. Apparatus

The BARS apparatus consisted of the assemblage shown in Fig. 1. This AR system was used inside a physical maze, and a representation of the maze programmed on the BARS and viewable through the SV-6 PC viewer is shown in Fig. 2. As previously stated, the type of AR implementation represented information that is not part of the natural scene.

The display used is a $16 \times 20$ manufactured by Micro Optical Corporation. The position of the display for the user is adjustable, but most users wore the display as shown in Fig. 1 (and is consistent with [9] and [10]), to maximize view-ability of the real world. This display represents the state-of-the-art in current production mobile display devices. We also believe that

Fig. 2. Microoptical SV-6 display and glasses used with BARS.

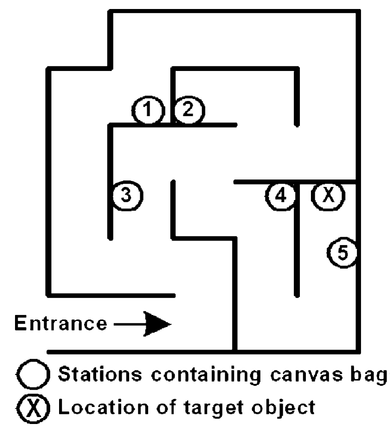


Fig. 3. Configuration of the maze with the locations of evaluation. points (stations), and the target object.

it is representative of displays that might be fielded in the near future. For example, the U.S. Army is using a physically similar device in its Objective Force Warrior Program.

A scaled plan view representing the maze, which is equivalent to that seen by the participant, is shown in Fig. 3. The map seen by participants in the display was white on a black background. Fig. 3 also indicates where the target object was placed. This placement of the target object, though, was not displayed to participants. Fig. 3 also indicates stations where spatially oriented questions were placed in appropriately sized canvas bags, attached to the wall, for the participant to answer during maze traversal. As with the target object, these locations were also not displayed to the participants during testing.

The size of the maze was approximately 15 ft $\times$ 18 ft, and this small size was due to limited space availability and resolution power of tracking hardware. There were no overt landmarks, except the bags. The lack of landmarks was intended to be representative of unfamiliar or low visibility spaces.

### B. Experimental Task

Each participant completed two task components. The primary task was to completely traverse the maze (including dead ends) before retrieving the target object. After the target object was retrieved, the participant was to immediately find the shortest way back to the entrance. The tradeoff between time and accuracy is an important consideration to the participant during the task. The secondary task, which was embedded into the overall demands, was to answer questions placed at five stations in the maze. The questions were placed in canvas bags, and were designed to query capacities (i.e., visual–spatial) used in the primary task. The purpose of the secondary task was to gather spatial information, and mitigate any possible traversal timing and accuracy related ceiling effect by placing additional requirements on working memory.

In a room separate from the maze, an informed consent form was completed and demographic information was gathered. Participants were then tested for spatial abilities using Parts 5 and 6 of the Guilford–Zimmerman Aptitude Survey [18]. These tests respectively measure a participant's spatial orientation and spatial visualization abilities.

The following actions represent each participant's sequence of events, once pretesting and accommodation to the equipment is completed.

1) The participant is positioned at the entrance of the maze.
2) A quick review is given of the procedure the participant is to follow.
3) The BARS is enabled by the experimenter, the participant is told to begin, and the timer is started (the timer is not visible to the participant).
4) The participant begins traversing the maze and viewing their map (if available) and area covered.
5) A canvas bag containing spatially oriented questions is found on the maze wall.
6) The participant answers the questions, returns the paper to the hanging bag and continues exploring the maze or finding the next bag.
7) Other bags are found, and the previous step is repeated.
8) The participant finds and retrieves the target object (a wireless tracker wand), and exits the maze through the shortest route.
9) The experimenter stops the clock, ends the BARS exercise, and retrieves the answers to the questions.
10) The participant removes the BARS, and begins the post hoc testing.

### C. Experimental Design

The present experiment used a between-subject design, in which the orientation of the display, either fixed north-up versus a rotating forward-up orientation (respectively, representing exocentric and egocentric displays) was crossed with a "continuously on" versus an "on-demand" display. Each of these conditions was compared to two control groups, either with or without a map. There were 20 participants (10 male and 10 female) in each of the six groups (refer to Table I for details on experimental treatments).

The two control groups were composed of a baseline control group without a map and a baseline with paper map. The baseline control group with no map (C_NM) wore the BARS equipment, but had no computer augmentation. These participants were provided with a compass. Timing started when the participant began moving in the maze. A variant of the baseline control group, control group with map (C_M), also wore the BARS, and were allowed to review a paper map prior to traversing the maze.

TABLE I
MATRIX OF EXPERIMENTAL TREATMENTS

| Control Group | On Demand Displays | Continuous Displays |
|---|---|---|
| w/o map (C_NM) | Fixed Map (X_D) | Fixed Map (X_C) |
| with Map (C_M) | Forward Up (E_D) | Forward Up (E_C) |

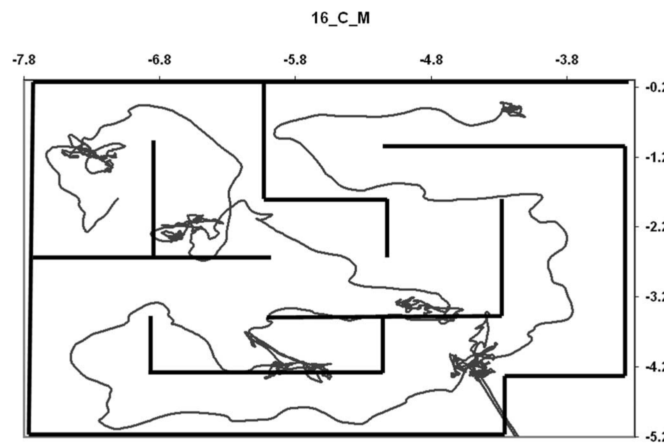


Fig. 4. Example of the kinematical trace of a single participant for maze traversal.

Timing started when the map was given to this control group participant. The map was taken from the participant when they entered the maze, and began traversal. No compass was provided to the participant in control group with map. These control treatments helped illuminate the speed–accuracy tradeoff, by requiring memorization, and is also reflective of situations that may be encountered in search and rescue navigation tasks, where limited visibility may preclude using a map. While many other control conditions are possible, these are felt to be most representative of what might be utilized in current situations.

There were two primary dependent variables 1) total and weighted time to complete the primary and secondary tasks and 2) percentage of the maze area covered. The percentage of the maze area covered was measured by observing the trace of the participant through the maze via a tracker. The participant's position and orientation was captured at 1 Hz. The stored track was overlaid onto the maze for analysis.

A sample of this kinematical trace is shown in Fig. 4.

## IV. RESULTS

The probability value $(p)$ is the most commonly used expression to test for statistical significance in experimental data [19]. Usually, $p$-values less than 0.05 are considered significant, but, when a prototype equipment is used, a value of 0.10 is acceptable [20]. Because of the prototype nature of BARS, we used a $p$-value less than or equal to 0.05 as significant and a $p$-value between 0.05 and 0.10 as marginally significant. If the $p$-value is less than 0.10, the null hypothesis is rejected. Nevertheless, the $p$-value is only a chosen level of significance that assumes the accuracy of the null hypothesis, and is heavily dependent

TABLE II
TOTAL TIME IN THE MAZE STATISTICS

| Treatment | Mean (sec.) | S.D. (sec.) |
|---|---|---|
| C_M | 347.4 | 88.2 |
| C_NM | 382.0 | 158.4 |
| E_C | 442.3 | 118.8 |
| E_D | 451.7 | 154.8 |
| X_C | 370.1 | 179.2 |
| X_D | 415.1 | 144.5 |

TABLE III
PERCENTAGE OF THE MAZE TRAVERSED STATISTICS

| Treatment | Mean (%) | S.D. (%) |
|---|---|---|
| C_M | 93.4 | 7.4 |
| C_NM | 96.2 | 5.2 |
| E_C | 94.8 | 5.4 |
| E_D | 98.2 | 2.9 |
| X_C | 93.5 | 11.9 |
| X_D | 97.6 | 5.1 |

on the sample size and the assumptions made for the particular test. In several cases, one can reach useful conclusions by comparing treatment conditions to control conditions using effect sizes. Effect sizes are simply differences in means weighted by pooled standard deviation.

The total time in the maze was subjected to an analysis of variance (ANOVA) [19]. Table II provides descriptive statistics for the total time in the maze in each condition. Participants in the control map condition (C_M) spent considerably less time in the maze than either of egocentric treatments, however, this difference was not statistically significant when the treatments were considered on an aggregate basis, $F(5, 119) = 1.677$, $p = 0.146$.

Further evaluation of total time in the maze was conducted using effect size analysis. The specific effect size technique was Cohen's [21]. A common thumb rule is to consider the effect size in absolute value of or greater than 0.8, large enough to conclude significance in the treatment condition with respect to the control condition; a value less than 0.2, small enough to conclude the treatment condition not significant with respect to control; and values between 0.2 and 0.8, moderate and difficult to make conclusions about the relationship between the treatment and the control [22].

Large effect sizes were noted between the control map and both egocentric treatments. The Cohen's values were 0.91 and 0.83 for the egocentric continuous treatment and the egocentric on-demand treatment, respectively, indicating a large effect when compared to the control map treatment. A moderate Cohen's value of 0.57 was noted for the exocentric on-demand treatment when compared to the control map treatment. These results showed that with respect to traversal time, the control map condition results in improved performance when compared to egocentric map display because better performance is reflected by a lower time to traverse the maze.

The percentage of maze covered, representing a measure of accuracy, was also subjected to an ANOVA. The between treatment effects were not significant, $F(1, 119) = 1.746$, $p = 0.130$. Table III provides descriptive statistics for the overall percentage achieved in each condition. As in the case of time, an effects size analysis was performed to assess significance between means. In this case, there were some significant values to report relative to the control map treatment, but with respect to display availability. The Cohen's effect size for the egocentric on-demand treatment was 0.85 indicating a strong effect. The exocentric on demand treatment was a moderate Cohen's value of 0.66. These values demonstrate improved performance in covering the maze when participants use an on demand display mode.

Note that there was a ceiling effect in the percent covered scores, and no large differences exist in the mean values. However, the standard deviation for each treatment was quite different revealing possible variation among participants. For example, the standard deviation changed by a factor greater than three between the E_D and X_C treatments indicating greater variability between participants in the X_C treatment than the E_D treatment.

Another result is from the derived weighted time. Weighted time is the total time divided by the fractional portion of the maze traversed before retrieving the target object. It is intended to penalize those participants who do not completely traverse the maze. As with the total time in the maze, participants in the C_M treatment exhibited better mean performance than the egocentric treatment. These two facets of performance frequently interact in terms of a speed–accuracy tradeoff. In the present experiment, participants engaged in such a trade, although the overall advantage in summed performance is clear because of the evident difference in accuracy.

There are other interesting observations from this series of experiments. For example, the standard deviations for time and percentage of the maze covered are higher in the X_C treatment than other treatments. The coefficients of variation (defined as standard deviation divided by mean) for X_C are 48.4% and 12.7%, for total time and percent of maze covered, respectively. This variation in the X_C condition can be due to some demographic considerations, and will not be discussed in this paper.

## V. DISCUSSION

This study examined the effects of using mobile AR compared to two, nonaugmented, control conditions (one with a paper map and one with a compass only) on navigation and wayfinding performance. The study focused on a "search and rescue" navigation task. In this task, individuals do not have an opportunity to study the space they are to traverse *a priori*. The time the individual spends learning their traversal route is therefore considered part of the total time to find their objective. Also, search and rescue requires accuracy in traversing the space. In the primary task, participants were asked to completely traverse the maze, find the target object, and exit the maze. They were informed that they would be measured on time and accuracy. The secondary task included answering spatially oriented questions while traversing the maze. Maze information was presented to participants in combinations of egocentric and exocentric formats and displayed continuously and on demand. Two control conditions were used; one with a paper map and one with only a compass.

Our first hypothesis is that wayfinding performance using a real-time AR map display would improve performance compared to the two control conditions. With respect to traversal accuracy, this hypothesis was met. In particular, the on-demand display availability resulted in improved capability. Even with a ceiling effect present, participants performed better with augmentation than either control condition. Such differences could be the critical factor between success and failure in dangerous situations. Performance with respect to time was not met. The control map treatment was statistically better than the egocentric continuous or egocentric on-demand display treatments. This difference was evident in both the traversal time and the derived weighted time.

The second hypothesis is that within the AR conditions, the use of an on-demand display as compared to a continuously on display would reduce the time, and improve accuracy on the primary wayfinding task and the secondary embedded task by providing the participant with control over the times, when the map is needed as a reference. This hypothesis was partially met. The percentage of the maze covered treatment showed improved performance by the exocentric "on-demand" treatment compared to the control treatment. The exocentric on-demand treatment showed improved performance when compared to the control map treatment, but the strength of the Cohen's value was at a moderate level.

This comparison with egocentric treatments might have introduced confounds in the results, though, because of infrequent anomalies in the display during the egocentric continuous treatment. The presence of aliasing and graphics anomalies could have been a distraction to participants. The distraction could have served as an uncontrolled benefit by alerting the participant to look at the display, or as a detractor by diverting the participant's attention away from another task. Better performance resulting from an on-demand map also provides participants with increased decision latitude and reduced mental strain, which is consistent with improved performance [23]. The present findings can be most usefully contrasted with a comparable analysis of wayfinding in VR [24]. The work of this paper, for example, showed no correlation between performance and spatial abilities (as measured with the Guilford–Zimmerman standardized tests), as contrasted with previously published positive results [24], which indicated some correlation.

### A. Design Guidelines

Several initial design guidelines can be extracted from the current findings.

1) On-demand displays should be used for AR to minimize divided attention and improve performance. These on-demand displays should not result in performance decrements, hence, hands-free operation might be useful as an activation strategy.
2) Augmented display contents should be either integral to the scene or be minimized to avoid divided attention issues for the user. The real world will usually prevail to a participant confronted with an augmented and real image. Therefore, integral augmented scene contents should be indistinguishable from the actual scene.

### B. Summary and Conclusion

Several significant findings emerged from the present study. The findings are based upon the specific configuration of AR used and the search and rescue task defined in this work. Principal among these findings is the benefit of the on-demand display mode compared to a continuous display. This benefit was particularly pronounced in the percentage of the maze covered treatment, where all statistically significant results showed benefits of an on-demand display.

Tracker coverage limited maze size to 15 ft $\times$ 18 ft, facilitating the memorization of routes. Also, while participants were not informed of the need to memorize their route, those participants given the paper map had to study and relinquish it before proceeding. Therefore, there is an implied requirement for the participant in this treatment to memorize the paper map. On the other hand, participants using AR proceeded immediately to traverse the maze when allowed to, and generally spent no time studying the augmented reality map before traversing the maze. This difference in strategy could have affected results with AR-enabled users not planning their route in advance, and employing a strategy of repeatedly planning their route and assessing their progress during traversal. Pretraining using BARS might mitigate these differences. Our present contention is that an obvious increase in the dimensions of the maze to be searched, and thus, higher navigational complexity will show the benefits of AR technology as working memory becomes saturated. A further experimental procedure upon these lines is currently in the planning stage. Our conclusion is that mobile AR is an exciting nascent technology holding much promise.

## References


[1] W. Barfield and T. Caudell, "Basic concepts in wearable computers and augmented reality," in *Fundamentals of Wearable Computers and Augmented Reality*, W. Barfield and T. Caudell, Eds. Mahwah, NJ: Lawrence Erlbaum and Associates, 2001, pp. 3–26.

[2] R. T. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, "Recent advances in augmented reality," *IEEE Comput. Graph. Appl.*, vol. 21, no. 6, pp. 34–47, Nov./Dec. 2001.

[3] A. W. Siegel and S. H. White, "The development of spatial representations of large-scale environments," in *Advances in Child Development and Behavior*, H. W. Reese, Ed. New York, NY: Academic, 1975, pp. 9–55.

[4] K. M. Stanney and G. Salvendy, "Information visualization: Assisting low spatial individuals with information access tasks through the use of visual mediators," *Ergonomics*, vol. 38, pp. 1184–1198, 1995.

[5] P. Milgram, H. Takemura, A. Utsumi, and F. Kishino, "Augmented reality: A class of displays on the reality-virtuality continuum," *Proc. Soc. Photographic Inf. Eng., Telemanipulator Telepresence Technol.,* 1994, vol. 2351, pp. 282–292.

[6] B. Witmer and W. J. Sadowski, "Nonvisually guided locomotion to a previously viewed target in real and virtual environments," *Hum. Factors*, vol. 40, no. 3, pp. 478–488, 1998.

[7] D. Waller, E. Hunt, and D. Knapp, "The transfer of spatial knowledge in virtual environment training," *Presence: Teleoperators Virtual Environ.*, vol. 7, no. 2, pp. 129–136, 1998.

[8] E. J. Arthur Orientation specificity in the mental representation of three dimensional environments, MN: Univ. Minnesota, 1996, unpublished.
[9] A. J. Aretz, "The design of electronic map displays," *Hum. Factors*, vol. 33, no. 1, pp. 85–101, 1991.
[10] A. J. Aretz and C. D. Wickens, "The mental rotation of map displays," *Hum. Perform.*, vol. 5, no. 4, pp. 303–328, 1992.
[11] S. Gillner and H. Mallot, "Navigation and acquisition of spatial knowledge in a virtual maze," *J. Cogn. Neurosci.*, vol. 10, no. 4, pp. 445–463, 1998.
[12] E. J. Arthur and P. A. Hancock, "Navigation training in virtual environments," *Int. J. Cogn. Ergonom.*, vol. 5, no. 4, pp. 387–400, 2001.
[13] N. I. Durlach and A. S. Mavor, Eds., "*Virtual Reality: Scientific and Technological Challenges*," Washington, DC: Nat. Acad. Press, 1995.
[14] J. Psotka, "Immersive training systems: Virtual reality and education & training," *Instr. Sci.*, vol. 25, pp. 405–431, 1995.
[15] S. Feiner, B. MacIntyre, T. Höllerer, and A. Webster, "A touring machine: Prototyping 3-D mobile augmented reality systems for exploring urban terrain," in *Proc. Int. Symp. Wearable Comput.*, Cambridge, MA, 1997, pp. 74–81.
[16] A. Clark *"Natural-Born Cyborgs: Minds, Technologies, and the Future of Human Intelligence,"* New York, NY: Oxford Univ. Press, 2003.
[17] B. F. Goldiez, "Techniques for assessing and improving performance in navigation and wayfinding using mobile augmented reality," Ph.D. Dissertation, Orlando, FL: Univ. Central Florida, 2004.
[18] L. J. Cronbach, "The two disciplines of scientific psychology," *Amer. Psychol.*, vol. 12, no. 11, pp. 671–684, 1957.
[19] D. Yates, D. Moore, and G. McCabe, *The Practice of Statistics*. New York, NY: W. H. Freeman and Co, 1998, pp. 791–832.
[20] D. Moore, *The Basic Practice of Statistics*. New York, NY: W. H. Freeman and Co., 1994.
[21] J. Cohen, *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed. Hillsdale, NJ: Lawrence Earlbaum Associates, 1988.
[22] J. Cohen, "A Power Primer," *Psychol. Bull.*, vol. 112, no. 4, pp. 155–159, 1999.
[23] R. A. Karasek, "Job demands, job decision attitude, and mental strain: Implications for job redesign," *Admin. Sci. Q.*, vol. 24, no. 2, pp. 285–308, 1979.
[24] R. P. Darken and B. Peterson, "Spatial orientation, wayfinding, and representation," in *Handbook of Virtual Environments: Design, Implementation, and Applications*, K. Stanney, Ed. Mahwah, NJ: Erlbaum Associates, pp. 493–518.

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