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Navigating through Virtual Environments: Visual Realism Improves Spatial Cognition

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Abstract

Recent advances in computer technology have significantly facilitated the use of virtual environments (VE) for small and medium enterprises (SME). However, achieving visual realism in such VE requires high investments in terms of time and effort, while its usefulness has not yet become apparent from research. Other qualities of VE, such as the use of large displays, proved its effectiveness in enhancing the individual user's spatial cognition. The current study assessed whether the same benefits apply for visual realism in VE. Thirty-two participants were divided into two groups, who explored either a photorealistic or a nonrealistic supermarket presented on a large screen. The participants were asked to navigate through the supermarket on a predetermined route. Subsequently, spatial learning was tested in four pen-and-paper tests that assessed how accurately they had memorized the route and the environment's spatial layout. The study revealed increased spatial learning from the photorealistic compared to the nonrealistic supermarket. Specifically, participants performed better on tests that involved egocentric spatial knowledge. The results suggest visual realism is useful because it increases the user's spatial knowledge in the VE. Therefore, the current study provides clear evidence that it is worthwhile for SME to invest in achieving visual realism in VE.

Introduction

The use of virtual environments (VE) has become increasingly widespread. In numerous professions, new techniques are introduced to simulate virtual situations to increase insight, teach skills, or test usability. For example, in product design, VE can provide scenarios in which prototypes are tested early in development.[1] Not only are expensive, time-consuming mockups avoided, but future use problems are uncovered and easily anticipated as well. However, VE are generally used only by large companies because of complexity and costs.

Only recently, with the technique becoming more accessible, has VE become feasible for companies with smaller budgets, or small and medium enterprises (SME). The feasibility of using a VE depends on a range of constraints, including (a) the experienced immersion of users, (b) the resources and knowledge required, and (c) the development time of the VE. In this work, we focus on the first constraint. This issue is investigated within the development of a new supermarket. In particular, we address the relation between immersion and human visual spatial cognition.

Slater et al.[2] stated that the immersive character of VE is determined by (a) the number of sensory systems (i.e., vision, sound, touch), (b) the extent that information is provided from any direction, (c) the extent that external noise is excluded, (d) the correspondence between the user's behavior and the system's feedback, and (e) the degree of sensory richness, or realism.

Without dispute, a multisensory VE aids immersion. However, for SME, such a setup is far from realistic considering the constraints they have. For example, with multisensory VE, the synchronization of the sensory modalities is both crucial and challenging and consequently is not feasible. A similar argument can be made for Slater et al.'s second requirement. A VE providing information from any direction (e.g., a CAVE) is still far too expensive for SME in terms of both purchasing and maintenance. The third requirement, external noise, can be well controlled with the choice of a suitable (noise-free) room for applying the VE. The fourth requirement, correspondence between the user and system, is necessarily always optimized, since counter-intuitive system feedback will lead to unnatural user behavior in VE. This leaves Slater et al.'s fifth requirement: realism. A certain realism can be achieved for all sensory modalities (e.g., odor, temperature, tactile, sound, vision). In general, the more realistic a modality needs to be, the more expensive it is to achieve the realism. Although the benefit of realistically

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mediated environments is evident (e.g., gaming), for other applications, it is less so. This fact also holds for the use of visual realism, the modality explored in the current research. In particular, we address users' visuospatial cognition, as this is of interest for the case under investigation: the supermarket.

VE enable an interactive, spatial exploration of environments, which is known to be beneficial. Pausch et al.[3] found a better performance on a spatial search task in an immersive VE compared to a desktop environment. Tan et al.[4] showed an improved visuospatial performance on various tasks with large wall-sized displays compared to desktop displays. For an overview on the use of VE with spatial learning from navigation, we refer to Darken et al.[5]

In general, spatial learning from navigation is thought to occur in three successive stages[6]: (a) *landmark knowledge:* the location of orientation points or landmarks; (b) *route knowledge:* a set of paths, turns, and directions to reach a destination, which is spatially related to the person self (egocentric); and (c) *survey knowledge:* a higher-order mental representation of the environment's layout, which is then no longer egocentric. Richardson et al.[7] provided evidence that the acquisition of spatial knowledge of VE follows the same stages as in real environments. Others showed that learning VE is highly predictive for learning similar real-world environments.[eg,8–10] This suggests that similar cognitive processes are involved in the two environments. Therefore, the stage model of Siegel and White[6] is relevant when determining the usefulness of visual realism in VE. Consequently, the use of visual realism increases users' route and survey knowledge. Additional evidence for this hypothesis is provided by Christou and Bülthoff,[11] who indicated the importance of the quantity of the information presented during navigation.

The current study extends these findings through exploring whether visual realism indeed enhances spatial learning in VE by assessing the effect on the acquisition of route and survey knowledge. Two distinct groups of users were placed in front of a large screen and guided through a photorealistic VE and a nonrealistic VE. Afterwards, spatial learning was tested in four tests that assessed how accurately they had memorized the route and the environment's spatial layout.

Materials and Methods

Participants

Thirty-two students of the University of Twente participated in the experiment in exchange of course credits. The participants were randomly assigned to the photorealistic VE (10 women, 6 men; mean age 21.6 years) and the nonrealistic VE (10 women, 6 men; mean age 22.4 years). One participant was discarded from the analyses after receiving the incorrect test environment. All participants were right handed, reported no known visual or neurological disorders, and were naive concerning the purposes of the experiment.

Materials and apparatus

The VE was a supermarket[12] (Fig. 1A) that consisted of several sections with groceries such as fruit, vegetables, meat, and milk (Fig. 1B). The basic objects of the VE were modeled with 3D Studio Max (Autodesk, Inc.) and subsequently created using Quest3D (Act-3D B.V.). Two versions of the supermarket were modeled: photorealistic and nonrealistic VE (FIG. 2). Note that the absence of semantic information in the nonrealistic VE made the supermarket unrecognizable as such. A desktop computer running Windows XP (SP2) with a 42″ Panasonic TH-42PY70 plasma screen (resolution of 1920×1080 pixels and frame rate of 60 Hz) was used to present the supermarket. Participants were seated in front of the screen at 150 cm distance in a darkened room. They used a standard keyboard and mouse to navigate through the VE: the up, down, right, and left arrows to walk; the mouse movements to look in any direction.

Procedure

Pretests. Before the actual experiment started, the participants completed pen-and-paper tests. First, participants provided demographic data. Next, they filled in an adapted version of the Game Experience Questionnaire (GEQ),[13] which distinguished three levels of experience with playing games. Participants then completed the Hegarty's Perspective Taking/Spatial Orientation Test[14] to assess their ability to imagine different perspectives or orientations in space. The deviation in participants' drawing direction determined their score.

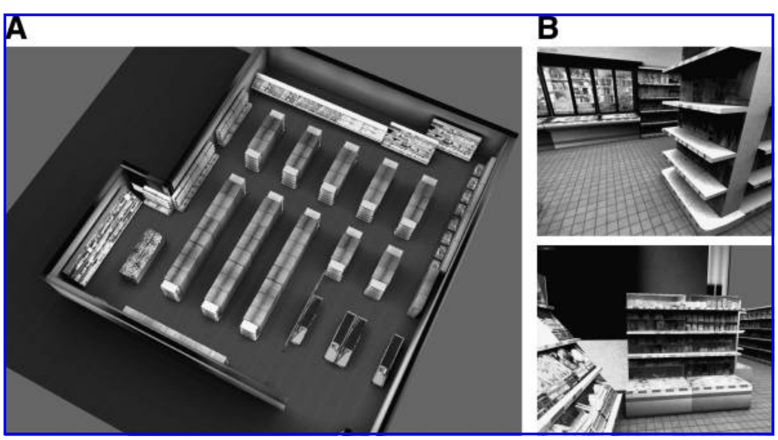

FIG. 1. **A:** Overview of the supermarket. **B:** Viewpoints of the various sections.

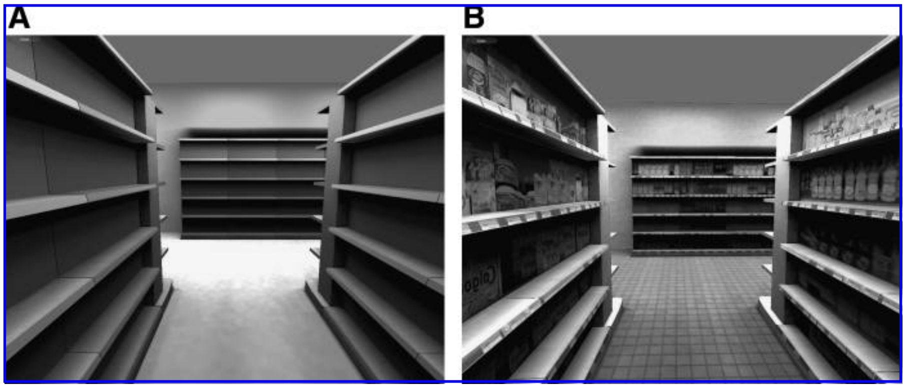

FIG. 2. **A:** The non-realistic VE. **B:** The photo-realistic VE.

Learning phase. In the learning phase, the participants initially familiarized themselves with moving around in the VE outside the supermarket. Afterwards, they were guided verbally to the entrance of the supermarket and then through it on a fixed learning route (Fig. 3). The learning route started and ended at the entrance of the supermarket. Each path was visited once, except for four that were not visited and two that were visited twice. There was no time constraint because there was only one route and pace possible. Nevertheless, time to complete the learning phase was recorded, accounting for the possibility that participants could stop to look around in the VE. Since the participants were already cognitively loaded in the visual domain, verbal instructions were used as guidance (e.g., go left here, at the end go right, or turn around). To motivate participants to actively learn the layout of the supermarket, they were instructed beforehand to pay as much attention to the VE as possible. Also, they were informed that their spatial knowledge of the VE would be assessed later on.

Test phase. After the participants completed the learning phase, they were tested on their knowledge of the supermarket. Four tests were used: two tests (the first and third) to assess their route knowledge and two tests (the second and fourth) to assess their survey knowledge. Participants conducted the tests individually.

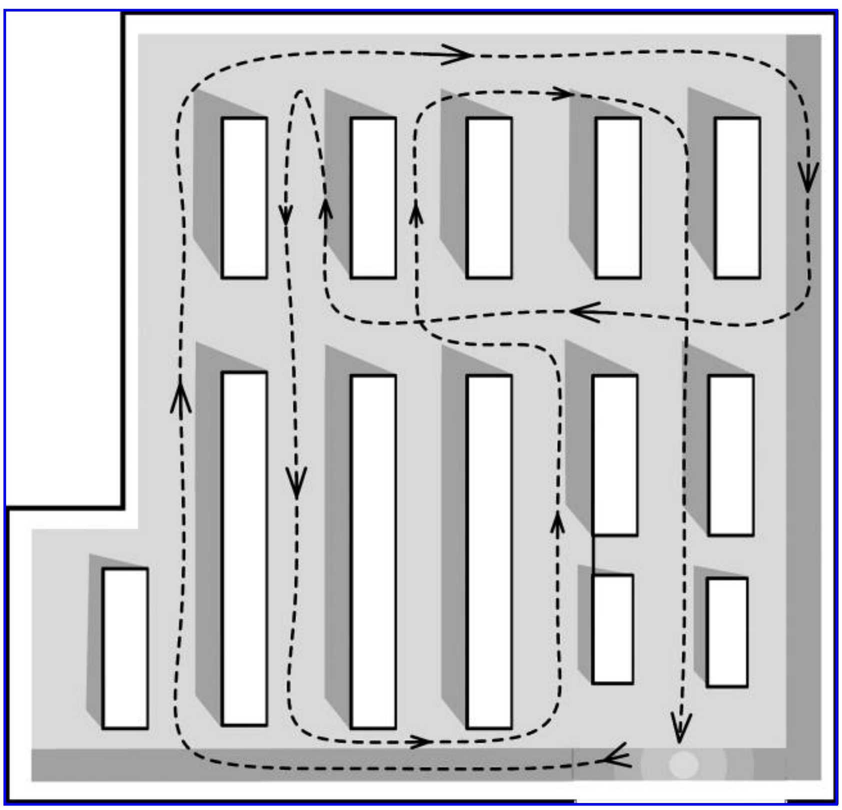

FIG. 3. The learning route through the virtual supermarket.

1. *Route reversal task:* Participants conducted a reversed route navigation task to assess their acquired spatial knowledge during the learning phase. Participants were instructed to walk the learned route in the opposite direction in the supermarket (see Fig. 3). Their route and completion time were recorded as precisely as possible with a stopwatch. Their accuracy was determined with a scoring method based on Asselen, Fritschy, and Postma.[15] Along the route were 28 decision locations in sequential order; each intersection of paths represented a decision location. When participants included such a location in their route, 1 point was given, and another point was given when they walked in the right direction onward. In addition, participants were given 2 points for a correct starting location and another 2 for a correct finishing location. Consequently, participants could obtain a maximum score of 60. After participants completed the route reversal task, they left the supermarket and proceeded with the remainder of the test phase on paper.
2. *Map identification task:* The participants were given 10 supermarket layouts, each on a separate piece of paper. Participants were able to rotate the maps to fit their mental reference view. They were asked to identify the correct map of the supermarket from among nine distracter maps. The distracter maps contained an incorrect number of aisles, an incorrect orientation of aisles, an incorrect outline, a mirrored outline, or a combination of these deviations. Participants were able to try twice to select the correct map. After the second attempt, it was recorded whether or not the correct map was identified. There was no time constraint.
3. *Route drawing task:* Participants were instructed to draw the learned route on the correct map of the supermarket with a pen on plain paper. Accuracy and completion time was recorded. The same scoring method as in the route reversal task was used.
4. *Viewpoint recognition task:* The participants were given 15 pictures of the supermarket from distinctive viewpoints (e.g., see Fig. 1, right frame). Participants were assessed an whether or not they recognized viewpoints and how they related these viewpoints to the map. They observed the picture and indicated the location and the direction of this viewpoint on a map. Completion time and accuracy were recorded. Correct locations and directions exceeding less than 90 degrees from the actual direction were scored as 1 point.

Results

Two multivariate analyses of variance (MANOVAs) were conducted to investigate our hypotheses: one for the accuracy and one for the completion time data, with task (route reversal, map identification, route drawing, and viewpoint recognition) as within-participants variable, VE (photorealistic, nonrealistic) as between-participants variable, and with the score on Hegarty's test as covariable. The self-reported game experience did not show any influence and hence was ignored in the analyses.

In the accuracy data, an overall effect for VE was found, indicating that participants in the photorealistic VE performed better than those in the nonrealistic VE, $F(4, 26) = 3.26$, $p < 0.03$, $\eta_p^2 = 0.33$. Between-participants effects are shown in Table 1. Furthermore, an overall effect for VE in the completion times data was found, which showed that participants in the photorealistic VE were faster than those the nonrealistic VE, $F(3, 27) = 3.65$, $p < 0.03$, $\eta_p^2 = 0.29$. The within-participants variable map identification was left out in this analysis because completion time was not recorded during this task.

A separate t test was conducted for the route completion times in the learning phase. A significant difference was found between the completion times of the photorealistic and nonrealistic VE ($t(30) = 3.00$, $p < 0.01$), $r^2 = 0.23$. In the photorealistic VE, participants took more time ($M = 291$ s, $SD = 138$ s) than in the nonrealistic VE ($M = 199$ s, $SD = 50$ s) to complete the learning route.

Table 1. Mean Scores of the Accuracy Data and Completion Times in the Photo-Realistic and Non-Realistic Virtual Environment (VE) on the Four Tasks

	Photorealistic VE	*Nonrealistic VE*	*MANOVA*
Accuracy (% correct)			F (1, 29)
Route reversal	67.2	58.0	2.70**
Map identification	50.0	37.0	1.84
Route drawing	58.0	62.7	1.75
Viewpoint recognition	65.0	52.5	2.90**
Completion times (sec)			
Route reversal	176.8	231.1	2.78*
Route drawing	152.3	145.9	0.12
Viewpoint recognition	444.3	505.7	2.10

Note: $^*p < 0.05$; $^{**}p < 0.01$.

Discussion

The current study investigated the usefulness of visual realism for VE, for this purpose a virtual supermarket was used. In an experiment, the effect of visual realism was tested on the acquisition of spatial knowledge of the VE. Participants were guided through a photorealistic or a nonrealistic supermarket and then tested on their knowledge. The results show that participants in the photorealistic VE were more accurate on the route reversal and the viewpoint recognition tasks than were participants in the nonrealistic VE. In contrast, no significant differences were found between the two supermarkets in the route drawing and the map identification tasks. Since average accuracy percentages were considerably lower than the maximum scores, this could not be a result of a ceiling effect.

The current study showed that participants during the learning phase in the photorealistic VE spend more time in the supermarket than those in the nonrealistic VE. This suggests that the participants attend longer to VE with visual realism. This is in line with the findings of Christou and Bülthoff,[11] who proposed that the degree of spatial learning in VE depends on the amount of information viewed. Probably, participants use visual realism to give the environment semantic value, which helps them to navigate through environments. Then, visual realism has the same role in the acquisition of spatial representations as landmarks, although less evident. We suggest that visual realism contributes to the content of VE and, with that, its uniqueness. Following the landmark, route, and survey knowledge theory of Siegel and White,[6] users form knowledge about the content of VE, enhanced by visual realism, and then form (egocentric) route knowledge. The last step, however, forming (nonegocentric) survey knowledge, is less certain to occur.

For SME, it is relatively easy to implement visual realism in VE in contrast to other modalities. Therefore, we focused mainly on vision. However, the effects on spatial cognition of using smell, touch, and sound in VE remains an interesting subject. Furthermore, the current study did not account for the minimum level of visual realism required to enhance spatial knowledge or a maximum level when spatial cognition is no longer affected. The exact relation between visual realism and spatial knowledge is not yet quantified. Future research has to further explore this issue. Nonetheless, this research can be of great interest for SME in that it shows where to invest when developing VE without overspending. Often, when developing VE, the use of innovative hardware is stressed. We suggest that it is not merely hardware that defines VE. Our study provides evidence that investing time and effort in the development of visual realism in VE is important because it increases users' spatial knowledge. Most of all, it provides a definite answer to the application of VE in fields other than the entertainment industry: yes, realistic VE do work better.

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Disclosure Statement

No competing financial interests exist.

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