Int. J. Human-Computer Studies 82 (2015) 1–10

Contents lists available at ScienceDirect

Int. J. Human-Computer Studies

journal homepage: www.elsevier.com/locate/ijhcs

User attributes in processing 3D VR-enabled showroom: Gender, visual cognitive styles, and the sense of presence ☆

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ARTICLE INFO

Article history:
Received 16 August 2014
Received in revised form
20 January 2015
Accepted 3 April 2015
Communicated by Dr. B. Lok
Available online 13 April 2015

Keywords:
3D
Virtual Reality
Virtual Environment
Gender
Cognitive style
Presence

ABSTRACT

Virtual environments (VEs) offer unique opportunities enabling users to experience real-time interactive objects and environments. Due to its dynamic three-dimensional (3D) presentation capability on two-dimensional screens, research has addressed the VE in relation to users' spatial cognitive factors. However, little is known about users' preferred cognitive modes for processing visual information and factors that affect visual cognitive processing in experiencing VEs. Research on gender differences in human–computer interaction has developed as a subfield approached from an interdisciplinary perspective that encompasses fields such as information science, marketing, neuroscience, and education. This study aims to investigate whether different visual cognitive styles influence the sense of presence (i.e., simulated experience in VEs) and how visual cognitions and presence affect user satisfaction of the 3D integrated system, as well as to uncover empirical evidence of gender influence on those relationships.

A total of 181 college students (90 men, 91 women) in diverse disciplines participated in an experiment using a VE stimulus and were given a questionnaire. The questionnaire was adapted to measure participants' tendencies to use object versus spatial visualization, their sense of presence, and user satisfaction in the VE. Using multigroup structural equation modeling, we examined 3D visual information processing and gender effects. The results identify the relationship among visual cognitions, presence, and user satisfaction in VEs. We find it interesting that the results demonstrated significant gender differences in satisfaction as well as in processing visual information that influences user experience of the 3D VR embedded interface. Whereas women's object visualization style was found to affect their sense of presence in VEs; for men, it was spatial visualization. This result supports and further explains findings of previous studies suggesting that gender effects account for differences in processing visual information.

1. Introduction

Since the advent of interactive, three-dimensional (3D) graphics, which debuted on the Internet with Virtual Reality Modeling Language (VRML) in 1994, web-based Virtual Reality (VR) has become a widespread medium for interactive 3D object demonstrations or simulations in many application areas. While the term Virtual Reality (VR) has been used broadly in various contexts, often referring to any system that allows the users to interact with virtual objects in a computer-generated 3D environment (Yoon et al., 2008), the focus in this study is web-based, non-immersive desktop VR. The use of VR changes how people experience and learn about an object by enabling virtual explorations. Despite seemingly obvious potential, VR-based interfaces have not been as prevalent and popular for e-commerce websites as might be expected, considering the maturity of computer and network technology. In order to better understand web-based VR applications and their acceptance, it is critical to address fundamental user issues.

User attributes such as spatial ability and learning styles in navigating and learning in a computer generated 3D virtual space, often referred to as Virtual Environment (VE), have been addressed in empirical verifications of ways to incorporate 3D VR technology into education and digital communication. A Virtual Environment (VE) is a 3D model of spaces displayed to users from an ego-oriented view using VR (Yoon et al., 2008). In order to respond to the challenges of finding effective and efficient digital environments to engage and motivate the users, educators and

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http://dx.doi.org/10.1016/j.ijhcs.2015.04.002
1071-5819/

researchers have explored ways of disentangling instrumental user attributes that result in better use of VE for various fields, including anatomy (e.g., Tan et al., 2012), cell biology (e.g., Huk, 2006), chemistry (e.g., Merchant et al., 2012), marketing (e.g., Clarke et al., 2006), and art education (e.g., Lu, 2008). While some investigators of instructional 3D environments found no significant association between the learners' spatial ability and functional learning (e.g., Tan et al., 2012), others found empirical support for user attributes related to spatial visualization and spatial ability inducing better engagement and further learning outcomes (e.g., Clarke et al., 2006; Huk, 2006; Imhof et al., 2012; Lai et al., 2012; Lu, 2008; Merchant et al., 2012).

Cognitive style is one of the user characteristics studied by human–computer interaction (HCI) researchers. It is a psychological dimension that represents consistencies in how an individual acquires and processes information (Ausburn and Ausburn, 1978; Messick, 1984). Among the various cognitive style dimensions researchers propose to study, only a few continuously draw attention. One of those is how individuals process visual information using different strategies: processing object properties and processing spatial relations. Studies have suggested that individuals have varying levels of object and spatial abilities (Velez et al., 2005). Among factors influencing the individual differences in visual information processing, gender has been one of the commonly recognized variables in cognitive psychology and related fields.

HCI research has explored the effects of users' visual cognitive style on their interaction with an interface (Chen et al., 2005; Cutmore et al., 2000). Previous studies established that spatial ability is a predictor of success in several technology-related disciplines (Strong and Smith, 2001); also, 3D VR technology can provide unique assets for assessing, training, and rehabilitating users' spatial abilities (Kaufmann et al., 2005; Passig and Eden, 2001). The VR interfaces offer a unique way of presenting and manipulating dynamic 3D objects and environments. The goals of HCI in 3D VR environments include the aspect of user experience that should provide an effective way to better understand cognitive aspects. Research is being conducted on the use of VR to improve spatial visualization (Kwon, 2003) and assess spatial abilities and skills (Kaufmann et al., 2005). However, little is known about users' preferred cognitive modes of processing visual information and factors that affect cognition processing in experiencing virtual environments (VEs).

In order to link visual cognitive styles and user experience in VR and provide a better understanding of those relationships, we focus on the sense of presence and gender differences in the visual information processing. Presence is widely considered to be the key attribute that defines the VR experience, as distinguished from other types of interface (Algharabat and Dennis, 2010). In this study, the main focus is how individuals' cognitive styles of visual information processing affect how users assess the interaction with a 3D VR interface as measured by the perceived sense of presence and satisfaction in VEs. Specifically, we attempt to provide additional insight into the relationship between cognitive preferences for spatial/object visualization and individuals' experience in VR, measured by examining the perceived sense of presence and gender effects.

2. Virtual reality and presence

VR is a computer simulation technology that uses 3D graphics and devices to provide highly interactive experiences. Some consider VR a fully immersive system utilizing special devices such as head-mounted displays, data gloves, 3D audio, and/or multiple large projective displays (e.g., CAVE) to enhance the users' experience or realism, and others use broader definitions with various levels of immersion (Yoon et al., 2008). For the present study, we used a VR system that runs on standard PCs without special input or display devices, allowing monitor-based viewing of 3D objects. The VR systems have attracted much attention for their unique and often more effective interface that allows users to interact with 3D objects and the environment in the three dimensions of width, height, and depth in real-time. The VR interfaces have been used in a variety of areas, including education, architecture, industrial design, engineering, military training, medicine, and virtual science laboratories. With the debut of VRML in 1994, desktop VR became available online and increasingly popular for various purposes, including product demonstrations. This unique experience is referred to as "virtual experience," which Li et al. (2001) defined as psychological and emotional states that viewers undergo while interacting with products in a 3D environment.

The key characteristic of VR experience has been identified as presence, the subjective feeling of being more involved with the virtual world (Biocca et al., 2001; Freeman et al., 1999). Some have used the term presence to describe enhanced levels of emotional involvement (Huang and Alessi, 1999; Västfjäll, 2003), not only in interactive media, but also non-interactive forms of media such as film and TV (Lessiter et al., 2001). Although presence has often been referred to as the feeling of "being there" in a 3D virtual environment, there are various definitions, including subjective presence versus objective presence, personal versus social presence, spatial presence, and so forth. Although different approaches can be used to measure presence, including behavioral and physiological methods such as changes in heart rate, skin conductance, and skin temperature, the most common way is users' self-reports. This is due to the subjective nature of presence (Schuemie et al., 2001).

Despite the difficulty in defining and measuring presence, there is a consensus that it has multiple aspects largely influenced by technological factors and user factors. Among user factors, gender is one of the independent variables considered in most of the presence studies. Heeter's (1994) study on gender differences in VR demonstrated that significantly more women than men were interested in VR learning experiences when they did not have to interact, whereas fewer women wanted to interact with either humans or computers in Virtual Learning. Witmer and Singer (1998) claimed that individuals' immersive tendencies affect their sense of presence, based on their empirical study with the Immersive Tendencies Questionnaire comprising three subscales: involvement, focus, and games. Similarly, there have been studies demonstrating the positive correlation between absorption and the sense of presence (Murray et al., 2007; Sas and O'Hare, 2003). Bracken's study (2005) found women to report more perceived realism in VR. On the contrary, Felnhofer et al. (2012) found significant differences between male and female participants in presence experiences in VR; men reported a higher sense of spatial presence, more perceived realism and higher levels of the sense of actually being in the environment than women, while women reported a higher sense of involvement.

Many HCI studies in VR have dealt with individuals' spatial ability because users experience the space in three dimensions through a two-dimensional (2D) screen. Previous studies suggest VR technology can provide unique assets for assessing, training, and rehabilitating users' spatial abilities (Kaufmann et al., 2005; Passig and Eden, 2001).

In addition to those studies demonstrating users' improved performance on tasks requiring spatial ability after practicing in VR environments, some studies, including Modjeska and Chignell (2003), suggested that individuals' different levels of spatial ability affect their performance in given tasks within VR environments. Modjeska and Chignell (2003) concluded their study with the suggestion that individuals' differences in spatial ability may determine the usability and acceptability of VR environments. Spatial ability studies have repeatedly reported gender differences, with men showing a better performance in a number of spatial tasks (e.g. Kryspin-Exner et al., 2012). Presence—a feeling of being in an environment—is thought to require proper spatial orientation in and navigation through the virtual environment (Nash et al., 2000). Hartman et al. (2006) claimed that VR-enabled interfaces might be more effective in measuring spatial ability, based on findings in previous research. Previous studies focusing on visual aspects in VE imply a close relationship between individuals' visual cognitive style and VEs.

3. Spatial visualizers versus object visualizers

Visual cognitive style is related to an individual's tendency and approach to process visual information. Until recently, research on individual difference in visual information processing styles and preferences has been largely based on the theory that imagery is unidimensional, and therefore individuals can be classified as good or bad visualizers (Paivio and Harshman, 1983; Richardson, 1977). Before neuroimaging technologies were developed, "verbal" and "visual" (e.g., visual-spatial) had been predominant distinctions for individual cognitive abilities in psychology and neurology. The verbal/visual-spatial distinction has been applied to the classification of individuals' preferred modes of information processing (e.g., cognitive styles).

According to this distinction illustrated in Fig. 1, visualizers rely primarily on imagery when attempting to perform cognitive tasks, whereas verbalizers rely primarily on verbal analytical strategies (Kozhevnikov et al., 2005). Developing accurate assessment tools has been one of the major challenges for verbal versus visual-spatial cognitive style research. Many attempts have been made to validate the visualizer/verbalizer cognitive styles dimension since the early 1970s, and there have not been many reliable findings. From neuropsychological studies indicating that higher-level visual areas of the brain are divided into two functionally distinct subsystems—the object and the spatial relations subsystems (Haxby et al., 1991; Mishkin et al., 1983), a newer approach to characterizing individual differences in cognitive styles has emerged.

In neuroimaging studies, spatial and object imagery tasks led to very different patterns of brain activity (Kosslyn et al., 2001). Particularly relevant to the current study is the well-established distinction between functions of the ventral visual system (which mainly processes shapes and other properties of objects, such as color and texture) and the dorsal visual system (which processes spatial relations). *Object visualization* is defined as "representations of the literal appearances of individual objects in terms of their precise form, size, shape, color, and brightness," and *spatial visualization* means "relatively abstract representations of the spatial relations among objects, parts of objects, locations of objects in space, movements of objects and object parts and other complex spatial transformation" (Blajenkova et al., 2006, p. 239).

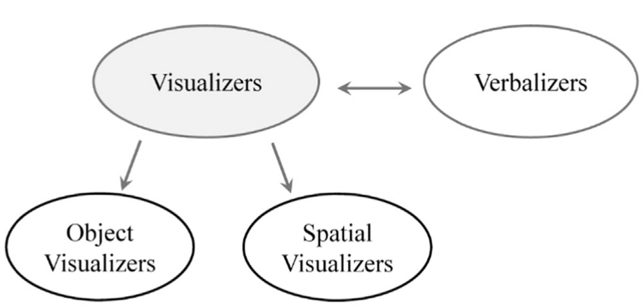

Fig. 1. Object–spatial–verbal cognitive style model (Kozhevnikov et al., 2005).

Object visualizers tend to construct colorful, pictorial, and high-resolution images of individual objects, whereas spatial visualizers tend to use imagery to schematically represent spatial relations among objects and to perform complex spatial transformations (Kozhevnikov et al., 2005). Chabris et al. (2006) established the validity of the dissociation between object and visual-spatial cognitive styles with 3800 participants. Using a self-report questionnaire, they found that object and spatial processing preferences were independent of each other without correlation. In addition, men, science majors, and people with video-game experience preferred spatial visualization, whereas women, humanities majors, and people with visual arts experience preferred object visualizations. It was also found that spatial visualizers performed better on mental rotation tasks and virtual maze navigation, whereas object visualizers were better on picture recognition tasks (Farah et al., 1988). A series of studies consistently demonstrated that these visual cognitive styles have high internal reliability—predictive, discriminative and ecological validity in both children and adults. Blazhenkova and Kozhevnikov (2009) reported that individuals' preferences to or self-assessments of object and spatial imagery are usually highly correlated with corresponding measures of object and spatial ability, respectively.

4. Research model and hypotheses

4.1. Visual cognitive styles, presence, and user satisfaction

Presence is an important mediator in the formation of virtual experience (Biocca et al., 2001), and website interface is known to influence the perception of presence (Hassanein and Head, 2007). Through interactive 3D technology such as zoom-in, rotate, or zoom-out images in a 3D website, 3D VR brings more vivid visual information to users than two dimensions, and interactive 3D technology has been credited with positively enhancing users' virtual experience (Kim et al., 2007). In addition, because VR is presented by different colors, shapes, and angles with a depth, users experience highly evoked psychological and emotional states. Such vividness and interactivity are core elements forming the sense of presence (Fortin and Dholakia, 2005). Among two kinds of visual cognitive styles (i.e., object and spatial visualization styles), object visualization is closely related to vividness and interactivity of products or other visual information. This means that object visualizers are more likely to respond positively to the vividness and interactivity of 3D VR, which leads to an enhanced sense of presence. Based on this logic, we propose the following:

H1. *Object visualization style has a positive impact on the sense of presence in VEs.*

Contrary to object visualizers, spatial visualizers tend to perceive each piece of visual information respectively and analyze their spatial relationships (Blajenkova et al., 2006). Their visual information processing involves more complex and rational thinking to predict the possible results (Velez et al., 2005). An assumption can be made that such cognitive aspects hinder forming some emotional states (i.e., the sense of presence). Many studies emphasize the emotional aspect of presence (Västfjäll, 2003), discussing that presence involves various experiential reactions in an artificial or illusory reality (Huang and Alessi, 1999). Spatial visualizers focus more on conducting an efficient information search or retrieval to perform complex spatial transformations, rather than experiencing 3D VR. Thus, spatial visualization style may negatively influence forming the sense of presence. Therefore, we propose the following:

H2. *Spatial visualization style has a negative impact on the sense of presence in VEs.*

Positive experience generally leads to effective user reactions. Previous studies demonstrated that presence is an important predictor of various positive user responses (i.e., satisfaction, patronage, attitude, or purchase intention) in VEs (Biocca et al., 2001; Freeman et al., 1999). Emotion evoked by 3D product presentation is known to influence the user response toward a website (Hassanein and Head, 2007; Jeong et al., 2009). Some of the studies suggest the close association of presence and satisfaction. Gunawardena and Zittle (1997) and So and Brush (2008) reported that presence is a very strong predictor of satisfaction within a computer-mediated conferencing environment. In the case of online learning, presence positively affected the satisfaction of both students and instructors (Richardson and Swan, 2003). This study, therefore, hypothesizes the following:

H3. *The sense of presence has a positive impact on user satisfaction in the 3D VR application*.

4.2. Moderating effects of gender

For a long time, many studies in various areas, such as psychology, social science, or HCI, reported gender differences in cognitive abilities (Yang and Chen, 2010). Among all cognitive abilities, spatial ability, which is closely related to visual information processing, is considered one of the sub-dimensions with the largest gender differences reported (Coluccia and Louse, 2004). In this study, we do not aim to reveal why males and females think and act differently or which gender outperforms on given tasks. Instead, we attempt to discover what differences between males and females exist in visual information processing and experience presented by 3D VR.

The classification of spatial and object visualization is supported by findings of gender differences. Previous studies demonstrated that males tend to perform better than females on a variety of spatial orientation and mental rotation tasks (Collins and Kimura, 1997; Geary, 1995) and that females perform better on an imagery vividness questionnaire (e.g., Campos and Sueiro, 1993). Researchers, including Sorby et al. (1999), Velez et al. (2005) and Yang and Chen (2010), have also confirmed the variance between genders regarding spatial ability. Meta-analyses of research have revealed gender differences in favor of males with regard to spatial ability (Voyer et al., 1995). Findings in cognitive ability studies persistently demonstrate gender differences in visual-spatial ability, with males performing better than females in tasks that are spatial in nature (Halpern, 2000). To confirm previous findings, Blajenkova et al.'s (2006) study with an object-spatial imagery questionnaire also reported that males had significantly higher spatial imagery scores than females, whereas females had higher object-imagery scores than males. Previous studies identified the moderating role of gender in using VE (e.g., navigation and online learning) (Cutmore et al., 2000; Hubona, 2004; Modjeska and Chignell, 2003). For example, Cutmore et al. (2000) conducted five experiments and reported that men obtained navigation knowledge using a VE faster than women did. In sum, men tend to focus on the spatial relationships and analytic structure in VE, whereas women tend to be sensitive to image vividness and interactivity. Based on this logic, the relationship between object visualization and presence in VE is stronger for women than men, whereas the relationship between spatial visualization and presence in VE is greater for men than women. Therefore, we formulate these hypotheses:

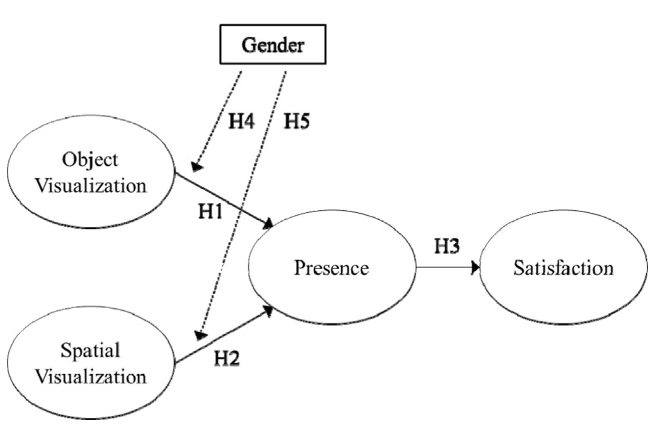

Fig. 2. Research model.

H4. *Gender moderates the relationship between object visualization and the sense of presence in VEs; specifically, the relationship is stronger for female users than for male users.*

H5. *Gender moderates the relationship between spatial visualization and the sense of presence in VEs; specifically, the relationship is stronger for male users than for female users.*

To investigate the relationships among visual cognitive styles, presence, and user satisfaction in VEs and the moderating effect of the gender on those relationships, we propose the research model illustrated in Fig. 2.

5. Research method

5.1. Participants

From 200 college students at a Midwestern university participating online, a total 181 were used for the analysis after data screening for outliers. The sample includes 90 men and 91 women, ranging in age from 18 to 37 ($M=20.48$, $SD=2.09$). Participants were recruited from various classes across the campus over a period of four months with the offer of extra credit or a gift certificate to a local pizza restaurant. Participants' majors include agriculture, business, design, engineering, medicine, journalism, and hotel management.

5.2. Stimuli

This study involved a VR system that enabled Internet users to browse living room furniture items (i.e., a chair, a couch, and a table) in a 3D VR showroom, as shown in Fig. 3. One of the great advantages of online VR applications is their capability to represent bulky, highly customizable products that are challenging to view in reality. Furniture was chosen for this study because it has attributes that can benefit from the unique features of VR technology, including testing a wide range of possible texture/finish options and instant mix-and-match with other furniture items. Participants were requested to explore furniture items and to answer simple questions on preference as if they were buying a set of living room furniture online. The system interface was designed to be optimized for a standard PC with at least a 1024 × 768 resolution monitor. To be able to view the VR content, participants were required to install a 3D VR viewing plug-in before starting the task. The virtual showroom with photographic 3D models of furniture was created using Autodesk 3D Studio Max, EON reality studio and EON viewer (http://www.eonreality.com). Users could use a mouse to navigate through the virtual showroom environment with zooming and panning options.

Using the system, participants viewed different furniture models among the list of thumbnail images on the right side of the screen; they reserved as many pieces as they would like to review

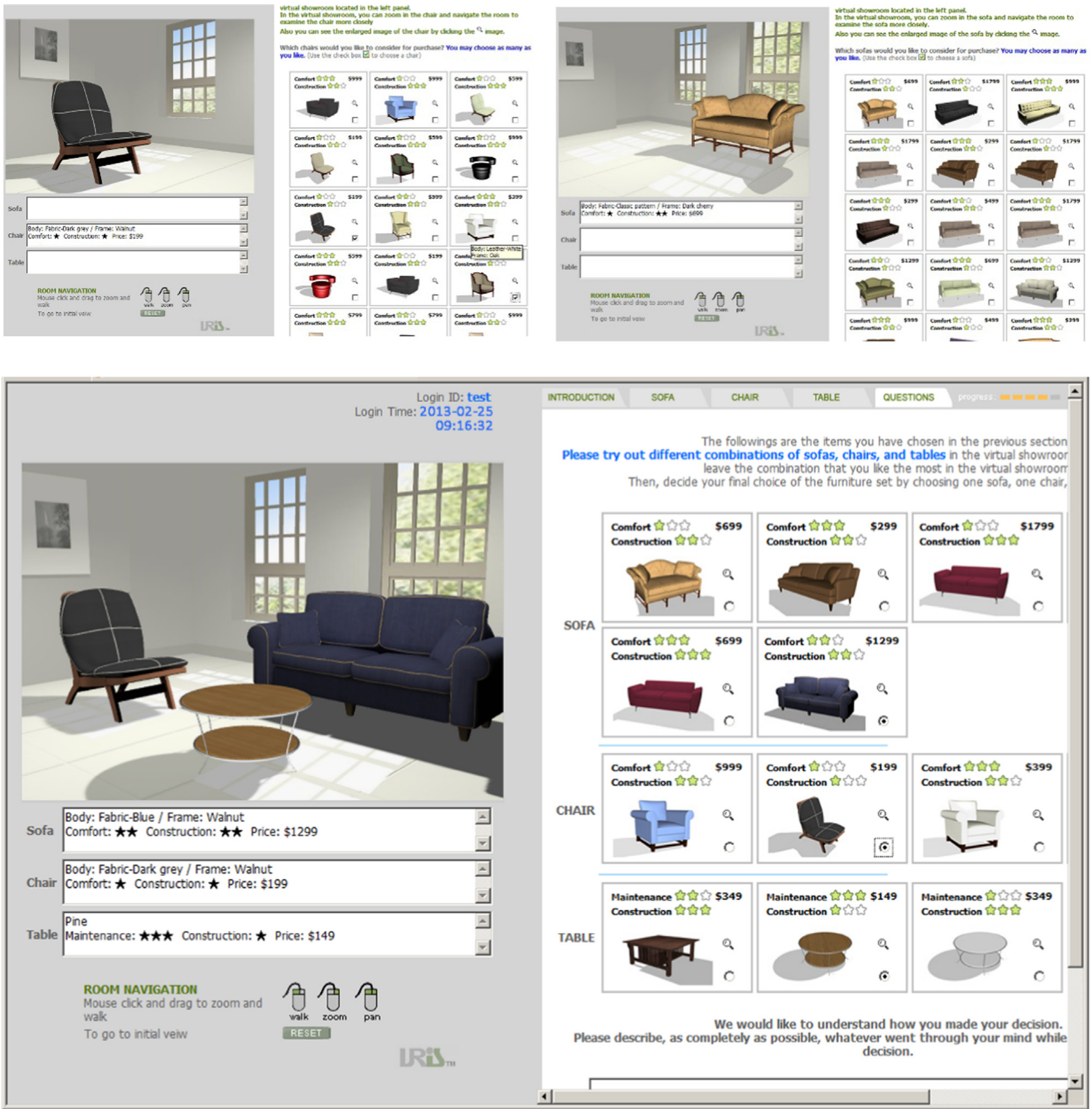

Fig. 3. Screenshots of the VR system interfaces used as stimuli.

later in combination with other furniture by checking the box next to a thumbnail image. The sequence was to select sofas, chairs, and tables separately and then view them together, with the option to make changes from among the checked items and then finalize the decision for one combination. The instructions asked participants to navigate the visual showroom space before finalizing their selections to make sure the 3D features are used. Initially, the VR integrated system was developed for the purpose of home furniture consumer market research. The series of tasks using the stimuli consist of common consumer survey questions.

5.3. Materials and procedure

We developed the questionnaire utilizing six items of the Object-Spatial Imagery Questionnaire (OSIQ), which measures an individual's tendencies to use object and spatial visualization (Blajenkova et al., 2006), three items of the Independent Television Commission Sense of Presence Inventory (ITC-SoPI) (Lessiter et al., 2001), which was adapted to measure presence, and three items of user satisfaction (McKinney et al., 2002; Lund, 2001) that measure overall satisfaction with the 3D VR system. The six OSIQ questions, adapted from the original OSIQ with 15 object and 15 spatial imagery questions, included three items for the object factor and three for the spatial factor. The presence scale items are from two factors, Spatial Presence and Engagement of the original ITC-SoPI, which consists of 38 questions in four factors, i.e., Spatial Presence, Engagement, Naturalness, and Negative Effects. The scales were developed based on sound international consistencies calculated in the coefficient alpha (Cronbach α as reported in Table 1). All items were validated in previous studies.

Data were collected using the participant's web browser via the service provided by Qualtrics.com, which allows users to complete

Table 1
CFA measurement model results.

Construct	Indicators	$n = 181$
Object visualization		
I can close my eyes and easily picture a scene.	Loadings	0.71
I remember everything visually.		0.70
I can easily remember a great deal of visual details.		0.64
	Cronbach α	0.73
	Composite reliability	0.71
	Average variance extracted	0.47
Spatial visualization		
I have excellent abilities in technical graphics.	Loadings	0.69
I was very good in 3D geometry as a student.		0.76
I am good at playing spatial games.		0.63
	Cronbach α	0.73
	Composite reliability	0.84
	Average variance extracted	0.48
Presence		
I felt I was visiting the places.	Loadings	0.61
I felt that I could move objects.		0.50
I felt involved in the displayed environment.		0.76
	Cronbach α	0.66
	Composite reliability	0.67
	Average variance extracted	0.40
Satisfaction		
Satisfied.	Loadings	0.71
Enjoyed.		0.76
Recommend to other people.		0.73
	Cronbach α	0.78
	Composite reliability	0.67
	Average variance extracted	0.54
	χ^2 (df)	75.63 (48)
	χ^2/df	1.58
	GFI	0.94
	RMR	0.06
	RMSEA	0.06
	CFI	0.95
	NFI	0.87

*Loadings = standardized estimates; n = sample size. All the loadings are statistically significant ($p < 0.000$).

custom-design questionnaires. After completing the given tasks using the VRIS, a VR integrated showroom system developed for the study, each participant completed sets of the OSIQ and the Presence measures, followed by questions asking demographic information (i.e., sex, age, and college major). Except for the demographic characteristics, all other items were measured using 5-point Likert scale ranging from 1 (totally disagree) to 5 (totally agree).

Given that participants' attention can diminish if completing the questionnaire at the same time as the experiment with the stimuli, a questionnaire was administered for the OSIQ and biographic information before the experiment. Using the VR system, the presence measure was administered immediately after the experimental task was completed. A randomly generated ID and password allowed participants to access the questionnaire website and each stimulus website. It took approximately 5–10 min to complete the given tasks to interact with the 3D VR interface, e.g., reviewing instructions, navigating the showroom, examining and choosing furniture items for the room, and reviewing the items together to finalize the decisions.

6. Results and analyses

When checking the results for missing data, nonnormality, outliers, or multicollinearity of the data, no serious problems were found. In the result of multivariate normality, the skewness of all observed indicators ranged from −0.92 to 0.04, which is less than 3.0, whereas the kurtosis ranged from −0.61 to 0.84, which is lower than 10, indicating that no normality problems were found.

Four steps comprised the analysis. First, confirmatory factor analysis (CFA) was conducted to test the fit and validity of the basic measurement model with total sample. Second, the basic structural model was tested with the total sample using structural equation modeling (SEM). In the third and fourth steps, to test the moderating effect of gender on the relationships between visual cognitive styles and presence, the structural relationships between male and female were compared by using multi-group confirmatory factor analysis (MGCFA) and multi-group structural equation modeling (MGSEM), respectively. All analyses employed the maximum likelihood estimation procedure of AMOS 18.0 (Chicago, IL).

6.1. Measurement model

The CFA results are contained in Table 1. All fit indices (χ^2/df = 1.58; RMSEA = 0.06; GFI = 0.94; AGFI = 0.90; CFI = 0.95) are acceptable within the range of recommended values. Next, the model's convergent validity was tested based on Hair et al. (2010). Factor loadings were highly significant ($p < 0.001$) and between 0.50 and 0.76, above the recommended minimum value of 0.5. The construct reliability (Cronbach α) estimates were also between 0.66 and 0.78, above or close to the recommended value of 0.7. Generally, the results support the convergent validity of the basic model.

Next, as in Fornell and Larcker's (1981) procedure, the discriminant validity of the model was assessed. Average variance extracted (AVE) of any two constructs and the square of correlation coefficient of the two constructs were calculated and compared. All squares of correlations between constructs of all combinations were between 0.00 and 0.39, which is lower than the AVE with a range of 0.40–0.54. The result showed that the four constructs were found to be independent of each other, proving their discriminant validity (Table 2). Finally, all values for composite reliability were within the range of 0.67–0.84, close to or above the recommended 0.7. Therefore, the model's discriminant validity was verified and was thus used in the structural model analysis.

6.2. Structural modeling (main effects)

After identifying the reliability and validity of the measures, the hypothesized structural model was tested using SEM. All paths were significant, and the goodness of fit indices of the proposed structural model met their generally recommended thresholds: χ^2/df=1.69, AGFI=0.90, GFI=0.93, CFI=0.94, and RMSEA=0.06 (Hair et al., 2010). That is, object visualization positively influenced presence, whereas spatial visualization negatively influenced presence. In turn, presence positively affected user satisfaction toward 3D VR, in support of H1–H3 (Table 3).

6.3. Multi-group measurement model (testing the measurement invariance)

In this step, we addressed the issue of measurement invariance. To compare inter-construct relationships between male and female, it is necessary to identify that both genders perceived each item and construct as the same structure. We followed Hair et al.'s (2010) procedures for testing configural invariance, metric invariance, and scalar invariance using MGCFA. To test measurement invariance, we conducted a comparison of three nested models (labeled as A, B, and C in Table 4). The latter model has a greater degree of invariance than the former. Generally, to compare the regression weight between two constructs in a multi-group SEM, the invariance of metric invariance (i.e., the invariance of factor loadings between groups) should be fulfilled. According to Cheung and Rensvold (2002), change in CFI of −0.01 or less indicates that the invariance hypothesis should not be rejected. In the result, the CFI remained unchanged between configural invariance and metric invariance model, proving support of metric invariance. It was validated that all constructs were perceived as having the same structure by both genders.

6.4. Multi-group structural modeling (testing the moderating effects)

To explore gender differences in the relationships between visual cognitive styles and presence, MSGEM was used to fit the basic structural model for the two groups simultaneously. Specifically, we perform a chi-square difference test between a model in which we restrict all path estimates and one in which we free the path in question (i.e., from visual cognitive styles to presence). Two Chi-square tests were conducted to identify the moderating effect of gender on the relationships between object/spatial visualization and presence. The Chi-square difference between two models (i.e., restricted model and non-restricted model) with one degree of freedom is greater than 3.84 ($p<0.05$), which means that the moderator effect works (strengthening or weakening the path in question).

First, to test the moderating effect of gender on the relationship between object visualization and presence, we compared the Chi-square between a restricted model and non-restricted model in which we free the path in question. In Table 5, the result shows that the fit of the non-restricted model improved significantly compared with the restricted model, offering support of H4. Second, as the result of the Chi-square difference test, the non-restricted model in which we free the path from spatial visualization to presence had greater improvement in the overall fit than the restricted model, in support of H5. The result showed that males and females processed visual information differently in VEs. The relationship between object visualization and presence was significant only for female respondents, whereas the path from spatial visualization to presence was meaningful only for male respondents. In addition, the directions of both relationships were opposite. For female respondents, the holistic imagery and vividness of a scene in 3D VR have an important role in positive virtual experiences. Male respondents tended to focus on the structure among objects and analyze their logical relationships in 3D VR, which hindered perceiving the sense of presence.

Table 2
Construct AVE and squared correlation matrix.

	AVE[a]	Standardized squared correlation			
		1	2	3	4
1. Object visualization	0.47	1.00			
2. Spatial visualization	0.48	0.12	1.00		
3. Presence	0.40	0.10	0.39	1.00	
4. Satisfaction	0.54	0.13	0.39	0.35	1.00

[a] AVE=average variance extracted.

Table 3
Standardized estimates of the hypothesized structural model.

Paths	Standardized estimates	Hypothesis	Support
Object visualization → presence	0.44***	H1	Supported
Spatial visualization → presence	−0.22*	H2	Supported
Presence → satisfaction	0.57***	H3	Supported

* $p<0.05$.
*** $p<0.001$.

Table 4
MGCFA measurement invariance tests.

Models	χ^2	df	RMSEA	GFI	AGFI	CFI
A. Baseline model (i.e., configural invariance)	143.21	96	0.52	0.89	0.82	0.91
B. Invariant factor loadings (i.e., metric invariance)	158.34	104	0.54	0.88	0.82	0.90
C. Invariant factor loadings and intercepts (i.e., scalar invariance)	179.41	114	0.57	0.86	0.81	0.88

7. Discussion and conclusion

As an important component of human intelligence, much research has been done focusing on individuals' visual-spatial cognitive abilities in various fields, including HCI (e.g., Kaufmann, 2003), psychology, and neurology. Individual cognitive differences have long been of interest to psychology researchers, and spatial ability is one of the several user characteristics they discovered that have potential applications in HCI. Despite previous studies attempting to address individuals' spatial ability levels and their performance in 3D VEs, the effects are not well understood of users' preferred cognitive style, which is associated with spatial visualization ability and visual information processing on user experience in VEs. To fill this gap, this study focused on the two different types of cognitive styles (i.e., object and spatial visualization) and gender differences in the visual information processing in 3D VEs. Specifically, we developed and tested a model composed of imagery styles, presence, and user satisfaction toward 3D furniture showrooms between genders.

A substantial amount of research has demonstrated that the ability to visualize 3D objects in one's mind is a key indicator of educational and career success in many fields. In HCI, research has shown that differences in individuals' spatial visualization ability lead to performance differences. Engineering and technology professions have been most frequently highlighted (Strong and Smith, 2001; Velez et al., 2005), but many more fields including architecture, design, and medicine have been pointed out by researchers (Sorby et al., 1999). In the same context, this study demonstrated that types of individuals' visual cognitive styles influence the sense of presence differently. Findings of this study showed that objective visualization style positively affected the sense of presence, whereas spatial visualization negatively related to it. This difference seems to be partly caused by the nature of presence, with its emphasis on aspects of emotional experiences (Västfjäll, 2003). Many studies have suggested that close relationships between imagery vividness/interactivity of websites and experiencing the sense of presence (Fortin and Dholakia, 2005; IJsselsteijn et al., 2000). The result of the positive relationship between object visualization style and presence provides support for this notion. Contrary to object visualization, spatial visualization style tends to hinder the emotional or instinctive experience of 3D VR by enhancing more cognitive and rational processing of presented visual information. This result was academically meaningful to clarify the independence of two dimensions in the visual cognitive style.

This study identified a visual information processing model in VEs, especially the causal relationship between presence and user satisfaction in 3D VR. In this study, the perceived sense of presence by VEs enhances user satisfaction with the 3D furniture showroom. This empirical finding can be helpful for e-business practitioners including web designers, programmers, and decision makers to support the importance of using 3D technology in their websites. The VR integrated interfaces can offer a cost-effective means of supporting retail by providing users a more confident and satisfying experience compared with 2D graphic interfaces (Yoon et al., 2008). In the same context, Stanney et al. (2003) reported that VR is effective for industrial, military, and other training applications. Yoon et al. (2008) also showed that VR integrated interfaces can be more effective than conventional 2D for 3D product review tasks.

Another interesting result is the identification of the moderating effect of gender on the relationships between visual cognitive style and presence in 3D VEs. This study discovered that the positive influence of object visualization style on presence in VEs was greater in female participants, whereas the negative relationship between spatial visualization and presence in VEs was stronger in male participants. In other words, compared with males, females tend to have a better sense of perceiving whole imagery and vividness of color, shape, texture, or other aspects of objects. Females would be better able to activate the object visualization in forming the sense of presence. The results of the moderating role of gender in visual information processing provided evidence that there exists a large variance in visual cognitive ability and preference between males and females, as seen in previous studies (Coluccia and Louse, 2004; Cutmore et al., 2000).

This finding on gender differences suggests that practitioners should recognize the gender or individual differences in processing the visual information in 3D VEs. Due to differences in visual cognitive styles, some use different cues than others for the same task. Decision makers of VR integrated interfaces need to consider different segments of user population for successful user experience and acceptance. For example, for female users, many functions to move, resize, or fit 3D objects into a web space can disrupt their focus during the 3D VE experience. While customizable spatial visualization might be a solution to expand 3D VEs into commercial areas for both genders, interaction features need to be carefully implemented considering the target gender.

To date, evidence of individual differences in VE navigation is by no means sufficient to ascertain performance advantages and disadvantages by gender or particular types of tasks, despite the growing number of studies tapping on individual user attributes and proficient navigation. As Martens and Antonenko (2012) noted in their meta-analysis and review of empirical studies on gender differences in VE navigation, more empirical studies to verify and determine the task difficulty threshold, as well as collecting data to better understand navigation performance by combining physical behavior and cognitive rationale, would be worthwhile lines of inquiry.

The results of this study suggest potential implications for future research on 3D VEs. First, this study focused on the whole process from visual cognitive style, presence, and user satisfaction with 3D VR, and therefore all constructs have only one dimension to simplify the model. Multi-dimensions of each construct in future studies could lead to more specific guidelines for scholars and practitioners. For example, a sub-dimension of presence such as vividness or interactivity could be considered in future studies. It could be interesting to study the inter-relationships among sub-dimensions of object and spatial visualization.

Second, further studies could consider various user reaction variables. This study used only user satisfaction in 3D VR as a user reaction variable. One suggestion is to analyze the influence of visual cognition on the level of a particular task performance, such

Table 5
Results of MGSEM.

	Male	Female	χ^2	$\Delta\chi^2$ (df=1)	H	Support
Object visualization → presence	ns	0.64***	227.68	7.31*	H4	Supported
Spatial visualization → presence	−0.55***	ns	228.79	6.20*	H5	Supported

* $p < 0.05$.
*** $p < 0.001$.

as information searching. Next, beyond gender, other individual difference variables that might affect visual information processing in 3D VEs also need to be studied. Several user factors, including previous experience, age, and gender, are known to affect spatial visualization ability. Previous studies have found that spatial ability varies by age and life experience (Strong and Smith, 2001), previous experiences (Deno, 1995), and learning style (Modjeska and Chignell, 2003). It would be interesting to expand the scope of research into different types of VE processing by those user factors.

Finally, the same study can be conducted with more immersive VR systems to explore replication of the results, as they tend to yield higher levels of presence. Interaction effects between immersiveness and user attributes influencing the sense of presence in different types of VEs can be also explored. The task selected for this study requires little navigation in the virtual showroom. Since the task itself for this study might have favored users with object visualization style, it will be worth testing with tasks requiring more spatial navigation to better assess the role of visual cognitive styles.

Over the past few years, 3D graphics and network technology have been undergoing rapid growth. With a better understanding of user characteristics and differences critical for successful interface design and technology integration, the idea of lifelike online shopping with optimal user experiences could become reality in the near future.

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