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

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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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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