Designing the next generation marketplace

by

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ABSTRACT

Virtual reality (VR) is predicted to be one of the next big retail trends that can transform the online shopping experience. Despite the surge of interest, important questions remain unanswered: how would VR change the current consumer online shopping behavior? If VR indeed has an impact on consumer behavior, what are the key explanatory factors for such an impact? For a novel interface such as VR, how do we effectively design a virtual market place that is easy to use? This dissertation explores these three questions in a series of three studies.

In Study 1, I compare a website to a VR store and examine how consumer behavior varies when they use a website and a VR interface. The results of Study 1 indicate that VR can be an effective shopping means especially for visually appealing hedonic products, thereby increasing the chance of exploring a hedonically superior product over a utilitarian product. In Study 2, I investigate the mechanism underlying consumers' preference for hedonic items and purchase intention with a VR store. The results of Study 2 reveal the distinctive roles of informativeness and playfulness of a VR store in predicting a product choice and subsequent purchase intention. In the last study, I explore how to design 3D user interactions that are easy to learn and use so that consumers can have a more informative and playful VR shopping experience. I developed three different prototypes and conducted a series of user studies to evaluate each interaction design.

This dissertation makes a number of theoretical and practical contributions to the broad academic fields ranging from design, marketing to human-computer interaction (HCI). Theoretically, this dissertation contributes to understanding the distinctive roles of informativeness and playfulness, two popular constructs studied in marketing and HCI research. From a practical point of view, this research finding is especially meaningful for online retailers who sell large-scale luxury or designer goods, one of the toughest product segments to sell online. The findings of this dissertation suggest that VR can help consumers to better appreciate the stylish and luxurious

appeal of products by allowing shoppers to more directly experience the life-size products. Moreover, this dissertation takes a further step toward designing 3D user interactions that can help consumers to easily navigate and manipulate the product in a virtual environment. I conclude this dissertation by presenting design guidelines that can aid more natural and intuitive interaction with a virtual product. The findings from this study, all combined together, provide insights for designers to understand how to create an effective virtual reality marketplace.

1. INTRODUCTION

The medium of virtual reality (VR) enables the new opportunity for consumers to virtually examine and try out the products before they purchase them. Virtual reality can drastically change the way consumers shop online by mitigating perceived risks associated with the traditional online shopping experience. Virtual reality holds great potential in the retail industry, yet little is known on how to use and create a virtual reality shopping interface. The explosive growth of interests calls for the convergence of seemingly distinct academic disciplines—design, marketing, and human-computer interaction (HCI). Utilizing an interdisciplinary approach, the primary goal of this dissertation is to **understand how best to use and create virtual reality marketplace so that consumers can make a more informed decision and have an enjoyable shopping experience**. In order to achieve this goal, I conducted three studies with their specific aims. In this introduction chapter, I present an overview of three studies and specify each study's objectives and research questions.

1.1. Motivation

Virtual Reality has seen an explosion of interest in recent years. Expensive hardware has been the biggest setback for widespread adoption, but the development of more affordable consumer-level devices substantially reduced the entry barrier for this new technology. In 2019, major VR headset manufacturers such as Oculus and HTC Vive released standalone VR headsets that no longer require a high-performing computer and expensive graphics cards, making VR devices more accessible to a broader audience. The market size of virtual reality and augmented reality is now predicted to reach $215 billion by 2021 (Deliotte, 2018). Virtual reality has impacted a range of industries including entertainment, education, tourism, and retail has become a prime candidate for VR applications, as evidenced by growing lists of retailers launching VR applications. In 2016, the world second largest e-commerce retailer, Alibaba premiered virtual reality shopping platform called "Buy+" for a smartphone-based headset. A year later, Amazon added an augmented reality (AR) component to its application, letting customers place various items in their house virtually before buying (Sun, 2018). In 2018, Walmart revealed its plan to introduce VR shopping applications.

Numerous articles and retailers tout its bright future; however, some remain skeptical about the likelihood of consumer adoption of VR. The lack of compelling content and poor interface design was pointed out as the greatest concern of consumers according to the latest survey result by a global firm, Perkins Coie (Perkins Coie, 2018). There exist little guidance and knowledge on how to effectively design a virtual reality user interface and companies are still experimenting with how to implement VR into their business strategy, causing large inconsistency in current VR shopping applications. Before companies invest more efforts in deploying VR technology, understanding the perceived benefit of VR shopping and how it differs from traditional online shopping is utmost importance for researchers and practitioners alike.

Accordingly, in this dissertation, I aim to address two interrelated topics: the *(1) impact of VR on the consumer decision-making process* and *(2) interface design of VR marketplace*. Study 1 and Study 2 address the first topic. Study 1 and 2 systematically compared VR to conventional online websites and explored how consumers perceive and behave differently when they used each shopping modality. The last study, Study 3, addresses the second topic. In Study 3, I developed three different VR shopping interfaces and conducted a series of user studies to identify the most effective interaction design that users find easy and enjoyable to interact with.

1.2. Research Scope: Target Product

The target product for this dissertation is *furniture* goods. Furniture was chosen as a subject of the study for three reasons. First, Suh and Lee (2005) observed that the effect of using VR is greatest for furniture because salient attributes of the furniture product, such as its size and fits, corresponds to the strength of the virtual reality. Stereoscopic displays of VR visualize objects' spatial information in a 3-dimensional space and helps consumers easily figure out the accurate size of the product (Suh & Lee, 2005). In addition to providing size and fit information, interactivity of virtual reality enables shoppers to place multiple 3D furniture models together into a virtual space, giving customers a better sense of how different sets of items would look together.

Second, the furniture industry is the major segment that has eagerly incorporated VR into a commercial strategy (Perkins Coie, 2018). Virtual reality has impacted a range of retail industries such as fashion, real estate, and travel industry; however, the market size for VR is biggest for the furniture industry (Neibauer, 2018). More than 20% of leading home goods retailer, including IKEA, Wayfair, and Lowe's, launched the VR application in the last couple of years. Large retailers such as Walmarts, Target, and Amazon introduced AR and VR shopping features to their mobile apps and this VR/AR service is currently available only for home furnishing products. By focusing on furniture items, the findings from this dissertation can provide immediate real-world implications for retailers to keep up with today's technology trend.

Third, furniture provides both utilitarian and hedonic benefits, hence fits well for the objective of the study. One of the goals of this dissertation is to explore in which context virtual reality does particularly excel over conventional shopping modalities. I propose that virtual reality can be particularly good at delivering product's experiential benefits; thus, can enhance the chance of exploring a hedonically superior product over a utilitarian product. Consistent with previous marketing research, we use the term "hedonic benefit" to refer to affective, experiential and enjoyment related benefits, and used the term "utilitarian benefit" to refer to functional and practical benefits of consumption offerings (Babin, Darden, & Griffin, 1994; Chitturi, Raghunathan, & Mahajan, 2008a; Dhar & Wertenbroch, 2000). In the context of furniture, for example, furniture's ergonomic design and the economic price is utilitarian benefit whereas its style and luxurious appeal are hedonic benefits.

1.3. Research Questions

With the overarching goal of understanding how best to use and design the virtual reality marketplace, this dissertation intends to achieve a number of research objectives and answer questions across all three studies. The first goal is to **understand the impact of VR on the consumer decision-making process.** In order to examine the relative benefits and potential impact of VR, I conduct comparative studies that compare VR shopping to conventional online shopping with websites. The following questions are addressed in the first study.

Study 1: Potential impacts of VR on the consumer decision-making process

1. How do the use of a VR store influence consumer's product evaluation and product choice when compared to traditional online shopping using websites?
2. What are the perceived benefits of VR shopping?

The second goal of this dissertation is to **identify underlying factors that may influence consumer-decision making process** for the VR shopping. In order to examine factors that influence consumers' perception and behavior, I created eight different versions of virtual stores that vary in the level of graphics quality, interactivity, and display types. The following questions are addressed in Study 2.

Study 2: Factors and characteristics of VR influencing the consumer-decision making process

1. How do the interface characteristics (i.e. graphics quality, interactivity, stereoscopic displays) of VR work together to influence the consumer decision-making process?
2. How the perceived level of informativeness and playfulness of the virtual store mediate the effect of interface characteristics on the consumer decision-making process?

After examining the effectiveness of VR shopping through Study 1 and Study 2, the next goal of this dissertation is **to develop an optimal VR user interaction that is easy to use and learn.** I particularly focus on interaction techniques using hand inputs. To better understand how to create hand-based 3D user interaction design, I created three different designs utilizing existing interaction techniques and conducted a series of usability tests. The ultimate goal of this study 3 is to provide design guidelines that can help user interface (UI) designers to create a VR shopping environment that is easy and enjoyable to use. The following questions are explored in Study 3.

Study 3: Designing 3D user interaction in virtual environments

1. What are the existing 3D user interaction design techniques for a virtual environment?
2. Among existing 3D user interaction techniques, which one provides better usability, efficiency, and accuracy in manipulating multiple large items such as furniture?
3. Hands are capable of a variety of gesture by its nature; pinch, grab, push and more. What would be the most intuitive and natural gesture to select and manipulate the large object?

In order to address the above research questions, this dissertation synthesizes existing knowledge from multiple disciplines ranging from the field of marketing, design and human-computer interaction. The findings of this dissertation can contribute to the understanding of the use of VR for shopping and offer suggestions about how designers can develop a virtual reality marketplace more effectively.

1.4. Research Overview

This dissertation utilizes an iterative research approach with three phases—1) identification, 2) analysis and 3) designing and evaluation. Each of the three studies addresses these three phases. The following writing briefly summarizes the study results.

First, Study 1 aims to *identify* the relative benefits of VR shopping and its potential impact on consumer product evaluation. In order to examine the potential impact of VR on product evaluation, I conducted a comparative study that compares participants' responses to VR shopping and to conventional online shopping with a website. Building on cognitive continuum theory (K. R. Hammond, 1988) and prior works on consumer choices between hedonic and utilitarian goods (Dhar & Wertenbroch, 2000; Roggeveen, Grewal, Townsend, & Krishnan, 2015; Shen, Zhang, & Krishna, 2016), I propose that VR can be an effective shopping means for luxurious hedonic products. The finding of the study supported such a hypothesis. Participants chose visually more appealing and luxurious hedonic products when they shopped with VR than when they used a website. In order to better understand the consumers' responses to VR, I also conducted follow-up interviews and examined participants' subjective opinions about VR shopping. Participants noted that two major benefits of using VR over a website are 1) informativeness—additional product information it provides such as product's size and fit—and 2) playfulness—fun and playful experience. These findings motivated the next study.

Second, Study 2 aims to *analyze* the underlying factor for consumer's preference for hedonic products in VR in greater depth. I particularly focused on the roles of informativeness and playfulness, two major benefits of VR identified in Study 1. In this study, I first explored how various interface features of VR, such as interactivity, graphics qualities, and stereo displays, work together to make VR shopping more informative and playful. I then further examined how the perceived level of informativeness and playfulness of VR shopping influence preference for hedonic products and subsequent purchase intention. The results of the study provide two meaningful insights. First, informativeness and playfulness influence the purchase decision-making process in distinct ways. More specifically, the playfulness of the shopping environment is the leading factor for consumers' preference for hedonic product benefits, whereas informativeness is a more important explanatory variable for subsequent purchase intentions. Second, the interactivity of VR significantly enhances perceived informativeness and playfulness; however, the role of graphics quality was found to be less critical for the VR environment. The findings of Study 2 indicate the critical roles of interactivity in enhancing perceived informativeness and enjoyment, which motivated the following study.

Lastly, Study 3 aims to *design and evaluate* different interaction techniques in a 3D virtual environment. The primary goal of this study is to understand how to design a hand-based 3D user interaction that results in better performance and is easy to learn. Hand inputs can be a powerful tool to control the complex computer-mediated tasks that require the manipulation of many degrees of freedom; however, little is explored on how to effectively design hand-based interaction for wearable VR devices. This study compares three widely-used interaction techniques: 1) touch and grab interaction, 2) multimodal interaction using gaze and pinch gesture, and 3) Worlds-in-Miniature technique. A comparison study reveals the strengths and weaknesses of each interaction technique. The result of a user study indicates that the worlds-in-miniature technique provides better usability and allows users to achieve a higher level of accuracy in manipulating multiple virtual objects. Contrary to the prediction, the conventional touch-grab interaction was not considered as natural and intuitive by many participants. From study observation and analysis, I present design suggestions that can aid 3D UI designers to integrate the best features of three interaction techniques and create more naturalistic interaction.

1.5. Contributions

I here provide a broad overview of the contribution of this research. More detailed writings about theoretical, managerial, and design implications are presented in Chapter 6. The outcome of this dissertation can contribute to both the academic communities as well as practitioners.

In Study 1 and 2, I explore the effectiveness of VR in altering consumer decision outcomes. From a managerial standpoint, it is worth examining whether using virtual reality influence consumer-decision outcome and can provide additional merits to conventional websites, before retailers make investments to create a virtual reality shopping application. The results of Study 1 and 2 suggest that the use of VR can be especially more helpful when selling the experiential luxurious product.

Academically, Study 1 and Study 2 build on previous works on technology acceptance model (Davis, Bagozzi, & Warshaw, 1992; Griffith, 2005; M. Koufaris, 2002; Venkatesh & Davis, 2000), hedonic versus utilitarian appeal (Chitturi, Raghunathan, & Mahajan, 2008b; Dhar & Wertenbroch, 2000; Roggeveen et al., 2015), and consumer decision-making process research (Ariely, 2000; Malhotra, 1982; Simonson, 1989). I explored how critical interface features of virtual reality—such as interactivity, graphic qualities, and stereo displays—work together to influence consumer’s perception and further affect consumers decision-making process. This approach differs from previous marketing research in a significant way. Many prior studies predominantly focused on the structural relationship between variables, thus they tend to analyze consumer responses based solely on one single stimulus (e.g., Kim & Forsythe, 2008; Pantano & Servidio, 2012). For example, the most common approach in previous retail literature is to show one single virtual reality environment to participants and ask them to indicate their willingness to use VR shopping (Ha & Stoel, 2009; Yim, Chu, & Sauer, 2017). Study 2 of this dissertation represents an initial attempt to examine how the unique design elements of the virtual reality environment may act in concert. The combined effect of different design elements on the consumer decision-making process has been less explored.

The primary contribution of this dissertation to the field of design lies in the exploration of more natural and intuitive interaction design. For a novel interface like VR, designing effective shopping environment requires more than simply providing a realistic view of the product. Interaction with virtual products in VR marketplace should appear natural and easy to use. The first step in designing an effective interface is to understand the current existing interaction techniques and identify the problem that can be improved. Three interaction designs are discussed and compared in Study 3. The results of Study 3 advance the current understanding of how users interact with a larger object like furniture in a three-dimensional virtual space and further provides real-world implications in designing a more effective VR shopping interface.

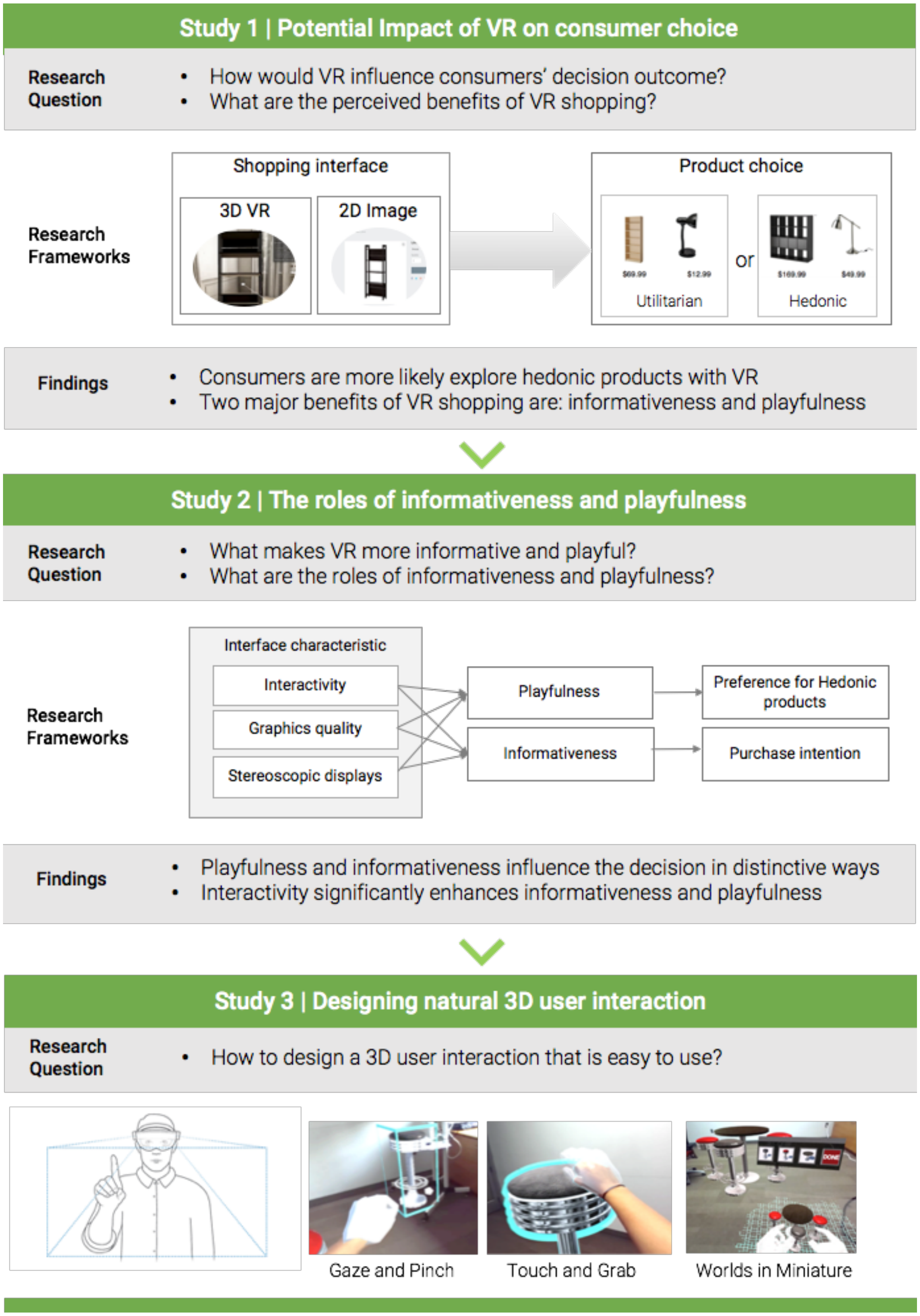


Figure 1.1. Graphic overview of three studies: In Study 1 and Study 2, I examined the effectiveness of VR shopping by comparing VR to conventional shopping interfaces. Study 3 explores the design of 3D user interaction.

2. BACKGROUND

This chapter provides a theoretical background on virtual reality and presents related works on its impact on consumers' behaviors. The purpose of this chapter is to provide a broad overview of prior works that explored the VR in the realm of design and marketing and thereby to give a context to understand the three studies. An in-depth review of literature pertinent to my theoretical models is presented in the *related works* session in the next three chapters in greater detail.

This dissertation builds from the prior marketing and human-computer interaction research that explored the impact of new technology and interface design on consumers' behavior. The recent development in consumer-level virtual reality devices has sparked academic interest in virtual reality shopping, but prior works on virtual reality shopping are rather limited, partially due to the relative novelty of virtual reality technology for general consumers (Yim et al., 2017). The majority of prior works that explored interface design are focused on the online website shopping context. Another problem in examining prior research on VR and consumer behaviors is the arbitrary use of the term VR, which often refers to a broad range of devices and interfaces including wall-projected stereoscopic displays, head-mounted devices, 360-degree video, and an interactive image.

In the remaining of this chapter, I clarify the terminologies relevant to virtual reality that I used throughout this dissertation. I then review the prior research on virtual reality and consumer behavior. Finally, I conclude this chapter with a discussion on existing 3D user interaction design technologies for virtual reality environment.

2.1. Definition of Virtual Reality

The term virtual reality (VR) has a number of definitions across a broad range of academic disciplines (Schroeder, 2008). A general consensus across the disciplines is that virtual reality can be distinguished from other media, in that it creates a strong sense of being present in a digitally fabricated environment (Schroeder, 2008; Steuer, 1992a). The concept of presence is the key to defining virtual reality (Steuer, 1992a). Gibson (1979) explained presence as the experience of one's physical environment; it refers not to one's surroundings as they exist in the physical world, but to the "perception" of those surroundings as mediated by mental processes (Gibson, 1979).

As early as 1992, Steurer argues that the definition of virtual reality should refer to perception and experience rather than defining it in terms of a collection of technological hardware. However, in empirical studies, the conceptualization of virtual reality often make reference to a particular technological system. The rapid pace of technological change caused researchers to use the term rather arbitrarily, as evidenced by the use of the term referring to a variety of hardware including computer monitors, head-mounted displays, projection-based displays and stereoscopic glasses (Steuer, 1992). In marketing literature, for example, Suh and Lee (2005) and Lee and Chung (2008) used the term virtual reality to refer to interactive 3D products displayed on desktop monitors. The same term has recently been referenced regarding more immersive devices, such as head-mounted displays in Grewal, Roggeveen, and Nordafalt's (2017) article.

Virtual reality (VR), augmented reality (AR), mixed reality (MR), and extended reality (XR); the glossary of terms used in the industry has nurtured the use of a variety of acronyms. In the virtual reality academic community, the term VR has been considered as an umbrella term that covers broad variations of the technological devices that all fall under a common feature—the creation of immersive experience (Milgram & Kishino, 1994). However, it is still important to note that these terms indeed refer to a different type of immersive experience. Based on such a notion, I used terms VR and AR to refer to different interfaces throughout the rest of the studies. The purpose of what follows is to clarify the terms that are used in the rest of this dissertation.

2.1. The glossary of terms

Virtual Reality (VR): Virtual reality generally refers to an immersive computer-simulated environment that replicates the real world and evokes the sense of presence to users (Steuer, 1992). Ivan Sutherland is the pioneer in the field who first implemented a virtual reality system in 1968 (Biocca, Levy, & Levy, 1995; Milgram & Kishino, 1994; Slater, 2003). The future of virtual reality he predicted is the immersive experience that engages all five senses—not only visual and sound but touch, sound, and smell as well—which he coined as "the ultimate display" (Sutherland, 1965). Although virtual reality has been considered as the umbrella term for all technological devices that generates an immersive experience (Steuer, 1992), in this paper, I use the term VR to specifically refer to head-mounted displays system that completely surrounds users with a digitally fabricated world.

Augmented Reality (AR): The major difference between AR and VR is the inclusions of the real-world view. Augmented reality is defined as "the superimposition of a virtual object on the real environment of the user" (Faust, Jasper, Kaufman, & Nellis, 2014). AR creates a superimposed overlay of the viewer in the electronically generated setting, whereas VR generally refers to the environment that is entirely generated with computer imagery (Milgram et al, 1994). Currently, the popular mediums of AR are mobile and tablet devices, as illustrated by the example of a mobile game called Pokemon Go. However, in this dissertation, I specifically focused on head-mounted AR devices. Microsoft Hololens and google glasses are two well-known examples of head-mounted AR displays.

Virtual Reality (Study 1 - 2) Augmented Reality (Study 3)

Figure 2.1 Virtual Reality and Augmented Reality: In study 1 and study 2, I used the head-mounted virtual reality device. Study 3 explores the use of augmented reality for interacting with virtual furniture products.

Head Mounted Display (HMD): A head-mounted display is a display device that often has a small display optics for eyes and it can be worn on the head as part of a helmet (Bowman, Kruijff, LaViola, & Poupyrev, 2001). Since the first release of an Oculus Rift in 2012, a head-mounted display became a primary component for the consumer-level virtual reality devices. The majority of virtual reality headset mainly display computer-generated imagery, but live imagery from the real-physical worlds can be also displayed with HMDs. This approach allows users to see both the real-world and super-imposed computer graphic image. For head-mounted displays, the combination of real-world view with a computer-generated image can be done by projecting the computer-generated image through a partially reflected mirror (e.g. Microsoft Hololens) or using a stereovision camera (e.g. ZED mini). In Study 1 and 2, I used the virtual reality head-mounted displays, an Oculus Rift headset, that only displays a computer-generated image. In Study3, I used the same head-mounted displays, an Oculus Rift headset, but combined it with ZED mini camera in order to create an immersive augmented reality environment. In the remaining of this dissertation, the former is referred to as VR HMDs and later is referred to as a wearable AR. Figure 2 shows the photographs of the example scene used in the studies.

Interactive 3D Product Viewer: In previous marketing literature, a number of researchers used the term virtual reality to refers to an interactive 3D product, with which users can freely rotate and examine the 3D product model with a mouse and keyboard (e.g. Lee & Chung, 2008; Suh & Lee, 2005). In order to avoid confusion, I used the term "interactive 3D product viewer" to refer to this form of the interface in the remaining of this dissertation.

Other Terms: Other technical terminologies associated with virtual reality devices are described below.

- *Field of View (FOV):* In the case of optical devices like AR and VR headsets, the field of view describes the extent of the observable world that is seen from the user' focused point. An average human eye has a field of view of 160 degrees (Doug A. Bowman et al., 2001). If the device delivers a small field of view, users can only see the portion of the virtual object.

- *Degree of Freedom (DOV):* In virtual reality interaction, the degree of freedom means the users' ability to move around in space (Snyder, Wilson, Leong, Klein, & Wilson, 2010). Many of the latest virtual reality devices provide the 6-degree of freedom: moving along with x, y, and z-axis, combined with changes in rotation on the x,y, and z-axis (Bowman, 1999). 3-degree of freedom usually only permits the user rotational movement and thus limits the capability to move around the virtual space. The Google Cardboard that only allows the user to look around with a 360-degree viewer falls into the latter category.

2.2. Virtual Reality in Marketing Research

The promises of virtual reality touted by marketing research include a wide variety of aspects including realistic shopping experience (Suh & Lee, 2005), virtual try-on (Kim & Forsythe, 2008), interactive advertising (Daugherty, Li, & Biocca, 2001), personalized shopping (Van Kerrebroeck, Brengman, & Willems, 2017) and visually rich shopping environment (Grewal, Roggeveen, & Nordfält, 2017). By far, the most popular research topic in the marketing literature has been a consumer's willingness to adopt the VR (e.g. Kim & Forsythe, 2008; Pantano & Servidio, 2012; Yim et al., 2017). Many persistently found that two distinctive factors are strong predictors for consumers' willingness to adopt the VR: informativeness and enjoyable shopping experience (Kim & Forsythe, 2008; Yim, Cicchirillo, & Drumwright, 2012). In this section, I discuss prior works that examined the informativeness and enjoyment of virtual reality shopping and their impact on consumer behavior.

2.2.1. Informativeness

The possibility to provide additional product information is the major benefit that made VR gain prominence in the retail industry. The use of virtual reality enables consumers to virtually experience the life-size scale product in a three-dimensional environment, thereby mitigating problem associated with the lack of physical access to inspect products in online (Kim & Foreyster, 2008). Although there are a limited number of prior work that directly examined the informativeness of VR shopping in the context of immersive VR HMDs, a considerable amount of research has explored the other relevant features—the use of interactive 3D product viewer (Suh & Lee, 2009), virtual try-on (Gallino & Moreno, 2018; Kim & Forsythe, 2008), and stereoscopic 3D advertising (Heeter, 2000; Li, Daugherty, & Biocca, 2002; Yim et al., 2012).

Defined as the process by which individual acquire product knowledge, consumer learning has been a fertile research topic in this area. Suh and Lee (2005) compared an interactive 3D product viewer to 2D still images and found that the consumer learning effect is greater with an interactive 3D product viewer. The result of their comparative study indicated that the use of an interactive 3D product viewer can significantly enhance both actual and perceived knowledge about the product. In a similar vein, Yim et al (2012) found that a stereoscopic 3D advertising increases the level of perceived product knowledge compared to the condition where the same product is advertised with 2D still images.

Information regarding the product's size and the fit is the key-value virtual reality can add. The primary benefits of VR lie in helping consumers to see the product in the context of use; previewing how a new sofa would look in consumers' own living room or virtually try on different sizes of clothes. Gallino and Moreno (2018) examined the value of "fit" information in the online retail context with actual sales data. By implementing a series of randomized field experiments, they found that offering virtual fit information increase conversion rate and order value, while reduces the return rate. All these prior works suggest that the use of VR can be a great mean to overcome the limitation of current online shopping.

2.2.2. Enjoyable Shopping Experience

Fun and enjoyable shopping experience is another primary benefit that virtual reality can add (Kim and Foreyster, 2008). Part of this excitement comes from the thrill of trying new technology (Psotka, 1995), but studies have shown that interactivity and realism of virtual reality are the key precursors for fun and enjoyable experience (Yang et al., 2009). Creative flexibility such as trying on multiple products virtually together can be a great source of the enjoyable shopping experience (Kim & Forsythe, 2008). With VR, users can further fulfill their shopping needs that would be difficult to achieve in the real world (Pantano & Servidio, 2012).

The prior empirical studies suggest that virtual reality can result in a substantially increased level of enjoyment as compared to conventional online shopping. Yim, Chu, and Sauer (2017) have demonstrated that individuals who experienced an interactive augmented reality shopping interface tend to feel a greater sense of enjoyment. Dynamic interaction in virtual interface enables a user to receive more direct feedback on one's action, which establishes an enduring sense of control. Ward and Barnes (2001) argue that having more control of the environment can be enjoyable because it motivates a user to be more focused and immersed in the experience. The realistic and interactive nature of virtual interfaces permit users to immerse themselves in the mediated environment, which results in loss of self-consciousness, sense of flow, and thus enjoyment (Ariely, 2000; Hoffman & Novak, 1996; Lombard & Ditton, 1997).

2.2.3. Impact of VR on Consumer Behavior

The study on consumer behavior and virtual reality, or similar interactive displays, has looked into various aspects of consumers' decision-making process: how consumers form the attitude toward the new technology (Kim & Forsythe, 2008; Yim et al., 2012), and how consumers decide to purchase the product (Gallino & Moreno, 2018; Yim et al., 2017). The literature review below provides a brief overview of prior works that examined these different aspects of the consumer decision-making process.

Consumers' attitude toward using VR

Consumers' attitude toward using the new technology has been the frequently employed measure for research into virtual reality and consumer behavior, partially due to the popularity of the Technology Acceptance Model (TAM) in academic research. Technology Acceptance Model explains how various factors determine users' decision on whether to use the new technology (Davis, 1986). The original model of TAM includes two factors as the major predictors for the acceptance of new technology, ease of use and usefulness (Bagozzi & Dholakia, 1999; Davis et al., 1992). TAM has been an effective research model for explaining the use of a new information system and application software. In the realm of online marketing, Koufaris (2002) suggest that TAM should be extended to include a variable that accounts for shopping enjoyment in order to better explain consumer's online shopping behavior. Accordingly, research into virtual reality and consumer behavior frequently have applied the extended version of TAM to provide empirical evidence on the relationship between usefulness, ease of use, enjoyment and consumers' willingness to accept VR.

While previous studies consistently report strong correlations between two factors, usefulness and enjoyment, into consumer's intention to use VR shopping (Daugherty, Li, & Biocca, 2001; Yim, Cicchirillo, & Drumwright, 2011; Yim, Chu, & Sauer, 2017), results on the relationship between ease of use and consumer's responses are rather mixed. In exploring an interactive virtual try-on application, Kim and Forysthe (2008) found that ease of use doesn't have a direct impact on consumers' attitude or willingness to use the virtual try-on application, but the ease of use plays the prominent roles in enhancing usefulness and enjoyment. Their study results suggest that ease of use precedes the usefulness and enjoyment of using new technology; that is, ease of use is the necessary condition that should be fulfilled first in order to make the new technology enjoyable and useful. Given the distinct roles of ease of use and the other two variables—usefulness and enjoyment—I examine the ease of use in a separate study. Study 1 and 2 mainly address the usefulness and enjoyment aspects of virtual reality shopping environment, namely informativeness and playfulness in these two studies, and ease of use is solely addressed in Study 3. More specifically, Study 3 explores how to design a virtual environment that is easy to use.

Product choice and purchase intention

Another frequently employed measure for research into virtual reality and consumer behavior is the purchase intention with VR technology (Suh & Lee, 2005; Yim et al., 2017; Yim et al., 2012) Purchase intentions are extensively used by academic researchers as proxy measures for purchase behavior (Schlosser, 2003) and are often measured with the set of questionnaire that asks respondents to indicate likelihood to buy the presented product (Morwitz, Steckel, & Gupta, 2007a). Suh and Lee (2005) found that the use of an interactive product viewer substantially enhances the consumer's purchase intention compared to when the same product was presented with still images. Similarly, Yim et al.'s (2017) study provide empirical evidence that the use of the augmented reality feature can result in enhanced purchase intention. While studies frequently examined purchase intention as a predictor of subsequent purchase (Morwitz et al., 2007a), Gallino and Moreno (2017) have looked at the actual sales data. They found that shoppers' average order is 1.6% larger when shoppers used the virtual try-on feature and their return rate was 5.2% smaller. The significant differences in return rate indicate that virtual reality technologies can be an effective way to alleviate consumers' uncertainty about placing an order online.

Before the consumer makes a final decision to purchase the product, he or she has to go through the process of evaluating alternatives to narrow down the options (Engle, Blackwell, & Kollat, 1968). Prior studies that looked into the relationship between consumer choice and product presentation yield insights into understanding the potential impact of VR on consumer choice. The recent study by Roggeveen and his colleague (2018) empirically demonstrated that more vivid and dynamic presentation modalities, such as video, increase the propensity to choose a hedonically superior item than when the same product is presented through a still image. Shen et al (2016) focused on the "touch" aspect of interaction and examined how consumer choice varies when consumers used a mobile tablet than a keyboard and mouse. The results from a series of their experiments indicate that consumers are more likely to choose a hedonically superior option with a mobile tablet. The authors further found that merely touching an image of an object can facilitate imagination of actual consumption. Although these studies deal with different sets of display interfaces than VR, their insights imply a systematic relationship between information display properties and consumer choice. Study 1 and 2 of this dissertation further examines consumers' product choice and purchase intention in the context of furniture VR shopping.

2.3. 3D User Interaction Design for VR

According to the latest survey results by a global law firm, Perkins Coie, poor interface design of VR was pointed out as the greatest concern of the current VR users (Perkins Coie, 2018). Despite rapid advancement in technological aspects of VR, the knowledge on how to design the virtual reality environment is still far from providing a sufficiently useful interface (Sherman & Craig, 2018). One of the common mishaps in designing virtual reality store is simply mimicking brick and mortar store or applying the component of online websites into the VR environment. Understanding how people would interact with a 3D virtual object is a critical component in designing VR application (Bacim, Kopper, & Bowman, 2013). In this section, I review prior work that explored 3D user interaction and discuss the existing techniques that can aid users to easily interact with a virtual object.

2.3.1. 3D user interaction

In computing, 3D user interaction is a form of human-machine interaction where users are able to move and interact with virtual objects in three-dimensional space (Bacim et al., 2013; Bowman et al., 2001). When users are surrounded by a virtual space wearing an HMD, conventional input devices such as the mouse and keyboard are often inappropriate. For example, with a wearable VR device, users may not be sitting down but rather walking around the physical space. Carrying the keyboard and mouse would be impractical in such a case. Technical limitations of the current form of VR devices is another factor that must be considered. The low resolution of displays make it difficult to read text-intensive information with VR and limited tracking space makes it challenging to design the large virtual reality environment where user can freely explore and navigate. It may appear that copying our real-world component into the simulated virtual reality world would be the simplest answer; for example, using a virtual agent who responds to voice command than using text inputs. However, people often find it inherently difficult to understand 3D space (Herndon et al, 1994; Bowman et al, 2001). 3D user interaction in virtual reality has its own unique characteristics that require new design guideline. What follows below discusses existing 3D user interaction techniques that had been studied in the field of virtual reality and HCI.

2.3.2. Typology of interaction tasks: navigation, system control, selection and manipulation

3D interaction techniques refer to interaction mechanism on how users can execute different types of tasks (Bowman et al., 2008). These tasks are broadly classified into three different groups: Navigation, System Control, and Selection and Manipulation (Bacim et al., 2013). The task of *navigation* is the most prevalent user action in the large-scale 3D environment (Bowman et al, 2001). Walking through the physical space is perhaps the most natural and intuitive way to navigate the space; however, this requires relatively large physical space and thus is not suitable for the typical room size environment. In order to overcome the challenges coming from limited tracking space, much prior research has looked into novel ways that support more efficient and natural navigation in a virtual environment. For example, several researchers looked into integrating locomotion devices such as treadmills into VR displays (Fung, Richards, Malouin, McFadyen, & Lamontagne, 2006; Slater, Steed, & Usoh, 1995) and some developed a new navigation mechanism such as target-based teleport in which users can simply point to the destination they would like to go (Ottosson & Grahn, 2008).

System control is the task where the user sends commands to the application and modify a parameter (Bowman et al., 1999, 2008). System control techniques that are widely used in VR include; a conventional graphical menu (e.g. button and icon), voice command, and gesture (Bowman et al, 2001, 2012). These two tasks, *navigation* and *system control,* have been heavily studied in the field of VR and a detailed overview of each technique are available in the book, "3D User Interfaces" (Bowman, 2001). Given that this dissertation is focused on VR furniture shopping, I specifically focused on a more relevant interaction task: how to select and manipulation the furniture item in VR.

2.3.3. Selection and manipulation: existing techniques

Study 3 in this dissertation mainly addresses *selection and manipulation* tasks with large furniture items. Selection refers to the task of picking one or more objects from the environment. Manipulation, closely related to the selection, is the task of changing a virtual object's scale, orientation and position (Bowman et al, 2012). The classical approach to design manipulation technique is to provide the user with a "virtual" hand, whose movement correspond to the movements of hand tracker. With the virtual hand, selection and manipulation simply involve touching an object with the virtual hand, then positioning or changing its orientation using a natural hand movement (Bowman, McMahan, & Ragan, 2012). Because this interaction simulates how people would interact with the real object, this virtual hand technique is considered to be the most intuitive interaction technique that is easy to learn and use (Bowman, McMahan, & Ragan, 2012). However, there is a fundamental problem with the virtual hand technique; a user can only reach to the object that is within his or her arm's length.

In order to address this issue, a number of techniques have been suggested. The ray-casting techniques (Liang & Green, 1994), virtual-ray emanating from input devices, are widely known techniques in VR that allows users to select and manipulate the objects in the distance. Another well-known technique is *Go-Go techniques* (Poupyrev, Billinghurst, Weghorst, & Ichikawa, 1996), that enables the user to extend their virtual arm's reach using a non-linear mapping of the virtual hand; when the users tried to reach the object beyond a fixed threshold distance, the movement of virtual arm accelerates. An alternative approach is to allow users to directly manipulate the relative scale of the virtual world. Inspired by the metaphor used in a book Gulliver's travels, Butter-worth et al (1992) propose the idea of the *3D immersive modeler,* in which users could grow or shrink their own size. The World-in-Miniature technique, proposed by Stoakley, Conway, and Pausch (1995) allows users to have two different viewports: actual scale size world and miniature size world. The user can indirectly select and manipulate the actual scale object by interacting with corresponding miniature size object.

In previous VR and HCI research, a considerable amount of effort has been devoted to developing the novel interaction that is efficient and precise, but relatively less attempt has been made to evaluate and compare existing interaction techniques (Bowman et al., 2006). In Study 3, I compare widely known interaction techniques and examine its effectiveness for manipulating furniture product in a virtual space.

2.4. Chapter Summary

This dissertation examined the impact of VR on consumer behaviors and design of VR interaction in a series of three studies. The aim of this chapter is to provide a broad background and context to the three studies. In this chapter, I discussed the definition of virtual reality, reviewed the relevant literature on virtual reality and consumer behavior, and examined prior works on 3D user interaction design for virtual reality.

In defining virtual reality, the rapid development of technology has made researchers use the term rather arbitrarily. In empirical studies, the virtual reality has referred to a variety of hardware including computer monitors, head-mounted displays, stereoscopic glasses, and projection-based displays. In order to avoid confusion, I use the term virtual reality to specifically refer to the head-mounted display that completely surrounds users with the computer-generated environment. The term augmented reality, in this dissertation, refers to the head-worn displays that create the overlay of virtual contents on the top of the real physical world. Study 1 and 2 focus on the use of virtual reality (VR) for furniture shopping. Study 3 explores the user interaction design for head-worn augmented reality (AR) system.

In exploring the benefits and impacts of VR, prior works suggest that informativeness and enjoyable shopping experience are two critical motivators to use VR for shopping. By converging the advantages of both online and offline shopping, the virtual reality marketplace can provide additional product information and deliver an enjoyable shopping experience to the user. In this dissertation, I particularly focus on the relationship between informativeness and playfulness of the virtual store and consumers' product choice and purchase intention.

In designing VR marketplace, understanding of natural and intuitive 3D user interaction design for a user is a critical component. For the novel interface like VR to be adopted quickly by the general population, it is critical that the interface is easy to learn and use. In this dissertation, I compare widely known interaction techniques and examine its effectiveness for manipulating furniture product in a virtual space. The systematic comparison of existing interaction techniques will allow researchers to scientifically scrutinize merits and demerits of each interaction, and furthermore, enable to identify the general design principle that can be applied to multiple VR applications.

STUDY 1 Impact of VR on Product Choice

The exploratory look into potential impacts and benefits of VR shopping

1. INTRODUCTION

The vivid and interactive three-dimensional (3D) virtual shopping interface enables consumers to simulate lifelike shopping experience over the virtual medium. With technology paving the way for easier access for virtual reality (VR) and 3D product visualization, e-commerce companies are readily pivoting toward 3D virtual shopping applications, yet the important questions have been less explored: What would motivate people to use VR for shopping? In what particular situations VR can be more advantageous than a conventional form of shopping through websites? A previous study, that examined the effectiveness of using VR, observed that VR can be a useful shopping means for the product whose size and the fit are critical concerns for purchase such as furniture goods (Suh & Lee, 2001). In this study, I take a further step and argue that VR can be an effective shopping means especially for visually appealing designer goods. In order to test the validity of this argument, I compare an interactive 3D virtual reality shopping environment to a conventional form of 2D website and examine consumer choices between utilitarian and hedonic products. Consumers' subjective opinions about VR shopping is also examined through the subsequent in-depth interviews.

I apply Hammond's (Hammond, 1988) cognitive continuum theory as a theoretical framework to explain the proposed interplay between shopping environments and product choice. I posit that when consumers shop with a dynamic 3D virtual environment, they are more likely to make an intuitive judgment and choose a more appealing option, a visually attractive hedonic product. On the other hands, a conventional 2D website induces analytical mindset thus enhances the likelihood of choosing a more reasonably priced and utilitarian product than a visually appealing luxurious product. While it may also be the case that some websites are highly interactive and visually immersive, this study does not address this type of scenario and primarily focus on a conventional static form of a website that displays information with still images and written forms.

The remaining of this chapter is structured as follows: I first review the prior works that examined how consumer shopping behavior varies depending on shopping environments. I then reviewed the cognitive continuum theory and discuss how I derive my predictions based on theoretical models. Next, I present the study that empirically tests my prediction. I finally conclude with a discussion of the implications this study provides to the field of retailing and design.

2. RELATED WORKS

2.1. Consumer Shopping Behavior and Shopping Environment

Traditional marketing studies categorized shopping behavior into two categories: goal-oriented and experience-oriented shopping behavior. Goal-oriented shopping is depicted as task-oriented, rational and deliberate behavior, that is mainly driven by a mission to procure the product that one needs. Experience-oriented shopping, on the other hand, is a shopping behavior that is not solely focused on the acquisition of a product, but rather for the sake of shopping process itself. Individuals with experience-oriented motivation enjoy the exploration of the store and thrill of the hunt and view shopping as a therapeutic means to cheer up the mood (Faber & Christenson, 1996).

Experiential shopping behavior is more prevalent in physical storefronts, whereas online shopping is more likely to be goal-focused (To, Liao, & Lin, 2007; Wolfinbarger & Gilly, 2010)). In a survey conducted by Wolfinbarger and Gilly (2010), the majority of shoppers said their recent online purchase was previously planned, while only a few mentioned that they had been just browsing websites without the specific plan of purchasing the product. In general, the affordances of online websites are more well-aligned with utilitarian benefits. Zeithaml, Parasuraman, and Malhotra (2000) conducted a series of focus group interviews to understand consumers' motivation for choosing online over other channels (e.g. brick and mortar store) and found that people preferred online channel for its convenience and easier product comparison.

While prior studies suggest the predominance of goal-oriented shopping in the context of online, the primary shopping motivation that would drive VR shopping is largely unknown. Marketers recognize that there is a larger portion of consumers who shop primarily for experience in the offline shopping context than in the online shopping environment (Wolfinbarger & Gilly, 2003), yet the question of whether such relative preponderance would transfer to VR has not been fully answered. Previous qualitative research on consumer adoption of VR provides meaningful insights into answering such a question. Kim and Forsythe (2008) conducted focused group interviews with shoppers who tried a virtual apparel try-on and found that the majority of respondents described the virtual try-on as *entertaining* and *amusing* as well as informative. Similiary, Yim, Chu, and Sauer (2017) conducted a text analysis with consumers' written reviews on virtual try-on and found that majority of comments described the virtual try-on as “cool” and “fun” experience.

These prior studies did not make a direct comparison between consumers' online and VR shopping behavior. However, one can infer from the preponderance of experience-related comments, such as *fun* and *entertaining* in VR description, that experience-oriented shopping may be more prevalent in VR storefront than in traditional online shopping environment. What VR shopping environment affords to users are generally well-aligned with experiential shopping. Once stepping into a virtual world, users can freely explore and try a creative combination of products, which is known to be a great source of enjoyment (Grudin, 2012). Such a different shopping environment in VR is likely to induce different responses from the shopper than how he or she would shop with a conventional online website.

2.2. Online Website vs VR store: Applying Cognitive Continuum Theory

The cognitive continuum theory was first introduced by a cognitive psychologist Hammond (Hammond, 1988) and has become one of the widely applied theories in human-computer interaction research (Standing, 2008). The theory addresses the age-old question of when and how people make decisions based on their *"intuition"* and *"analysis."* Hammond defines intuition and analysis as two modes of cognition that can be placed at the ends of a cognitive continuum, where "intuition" refers to a rapid and less controlled information processing, and "analysis" refers to a slow and systematically controlled information processing. One of the important principles of the cognitive continuum theory is a task-cognition inducement principle. The task-cognition inducement principle explains the compatibility of cognition types with a given task, that is whether individuals rely on their intuition or analysis is contingent upon a specific task (Hammond, 1988; Hammond, Grassia, & Pearson, 1987). For example, a task that displays information in terms of numbers or logical symbols better supports analytical thinking. In contrast, a task that displays the same information with multiple cues such as a video relatively imposes higher cognitive loads, which in turn, lead individuals make a snap judgment based on their intuition (Hammond, 1988; Hammond et al., 1987).

Table 3.1. Task characteristics of Analysis and Intuition Inducing tasks

	Analysis-inducing	Intuition-inducing
Display characteristic 1. Number of Cues 2. Redundancy 3. Displays of Cues	 Low Low redundancy Sequential	 Large Large redundancy Simultaneous

In applying the cognitive continuum theory to online shopping context, the display characteristic of a 2D website and an interactive 3D virtual environment can illustrate the classification of task inducing properties along the *analysis-intuition* continuum. The analytic interface is characterized by an information display that is organized in sequential and systematically manner (Mathwick, Malhotra, & Rigdon, 2002). The intuitive interface, on the other hands, is characterized by pictorially presented information with a large number of redundant cues that are presented simultaneously (Mathwick et al., 2002). Text-based information and a menu-driven website that presents the product with static 2D images fall into the end of *analysis* continuum. An interactive 3D environment tends to present a product in a more dynamic format with multiple sensory cues than a website, thereby falls into the end of the *intuition* continuum. In this study, I examine the interplay between shopping interface—whether it falls into analysis inducing or intuitive inducing interface—and consumers' product choice.

2.3. The interplay between the shopping environment and product choice

Recently, the handful number of marketing literature has advanced the idea that individual shopping behavior and choice can be influenced by shopping modality (Mathwick et al., 2002; Roggeveen et al., 2015; Shen et al., 2016). Mathwick, Malhotra, and Rigdon (2002) compared a website to a catalog and found that the catalog is more likely associated with experiential shopping than a website. A recent study of Roggeveen, Grewal, Townsend, and Krishnan (2015) compared a still image to a video and empirically showed that consumers are more likely to choose a luxury hotel when the same set of hotel rooms are presented with a video than with still images. In this study, I extend these findings to the domain of VR and explore how a 3D virtual environment, compared to a 2D website, might influence a consumer choice.

I posit that a static website would better support a systematic analysis of the product's price and specification, whereas a dynamic virtual environment would better facilitate the appreciation of the product's visual appeals. A key premise underlying our claim is that static 2D websites impose relatively lower cognitive loads thus permit users more mental resources to engage in analytical thinking. A conventional website presents product information in a more systematic and sequential manner than VR HMDs that surrounds users in an immersive environment. As a result, it is relatively easier for users to decompose information and analyze product price and specification into critical decision points (Mathwick et al., 2002).

In contrast, a dynamic 3D environment presents users multiple cues simultaneously; thus, the task of analyzing a product's price and specification occurs with relatively depleted processing capacity. There is converging evidence that consumers are more likely to choose a more appealing product when information processing is impeded (Dhar & Wertenbroch, 2000; Shiv & Fedorikhin, 1999). For example, Shiv and Fedorikhin (1999) have shown that when participants' processing capacity is depleted, the likelihood of choosing a chocolate cake over salad increases. A chocolate cake here represents a *hedoni*c choice, that spontaneously evokes positive affective responses, whereas a salad represents a *utilitarian* choice whose healthier benefit should be deliberately analyzed. Along the same line, a dynamic 3D virtual environment, where information processing is more cognitively taxing than a website, may lead consumers to favor a visually appealing hedonic choice than a reasonably priced utilitarian choice.

> *Hypothesis 1:* A static 2D website better supports a systematic analysis of the product's price and specification; thus, will enhance the chance of choosing a product that is superior on utilitarian benefits (a reasonably priced and functional good).
>
> *Hypothesis 2:* A dynamic 3D environment better supports an intuitive judgment of the product's visual aesthetics; thus, will enhance the chance of choosing a product that is superior on hedonic benefits (a visually appealing and luxurious good).

3. PILOT STUDY

Before examining the hypotheses with a VR environment, I conducted a pilot study with an interactive 360-degree product viewer. The interactive 360˚ product viewer and a website format carried the same set of speakers as seen in figure 1. We carefully designed two interfaces to ensure consistency (i.e., same font style and size, retrieval time). With an interactive 360˚ product viewer, users can zoom and rotate the speaker. The website format presents the same product with 5 images taken from different angles. Participants could proceed to an individual product page, examine multiple photographs by clicking thumbnail images and zoom in on mouse hover, all of which are standard user interface design for online websites (Nielsen, 2006). In order to ensure that our choice of the hedonic speaker is visually more appealing than the utilitarian one, a separate pretest was conducted with 32 participants recruited from Amazon's Mechanical Turk (56% female, average age = 32.84; *SD* = 8.05). Amazon Mechanical Turk (MTurk) is a crowdsourcing tool that allows a requester to recruit a specific population. A number of prior literature that compared Mturk to the traditional face to face survey methods found that the results across the samples for the same task were almost indistinguishable, suggesting MTurk can be a valid way to recruit representative samples (Casler, Bickel, & Hackett, 2013). Pretest participants were randomly assigned to either 2D or 3D interfaces and were asked to rate the two speakers' visual attractiveness on a scale from 0 to 10. The hedonic speaker was rated as visual more appealing for both conditions.

106 participants (58% female, average age = 34.06; *SD* = 9.87) were recruited to complete the study from Amazon Mechanical Turk. Participants were randomly assigned to a website or an interactive 360˚product viewer condition. Participants were encouraged to examine two sets of the speakers as long as they desired before choosing one particular model they would like to purchase. An analysis of covariance (ANCOVA) was performed to test our hypotheses. Participants' gender

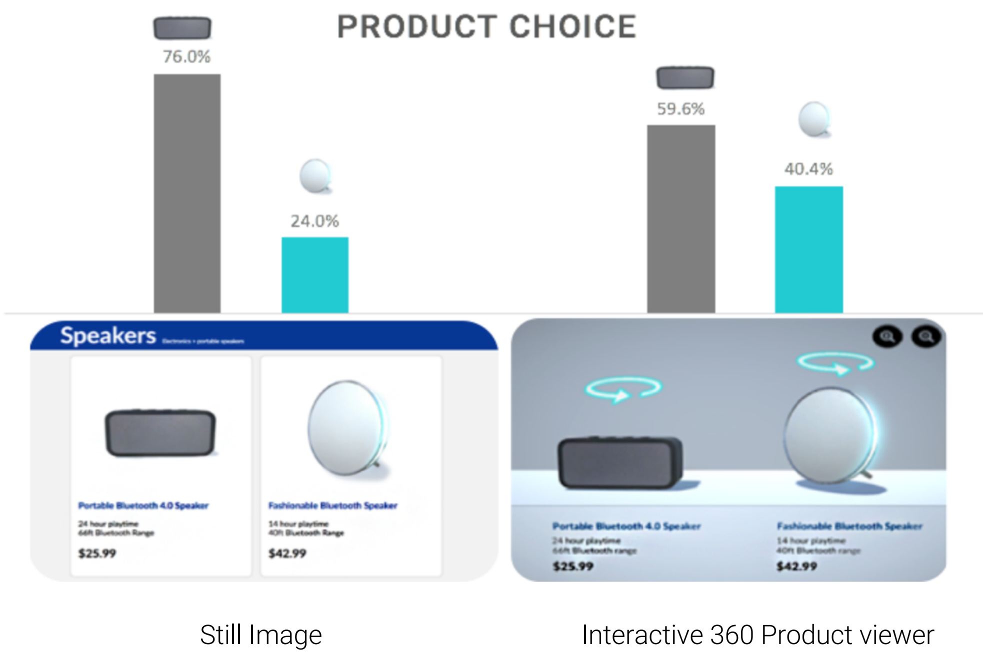
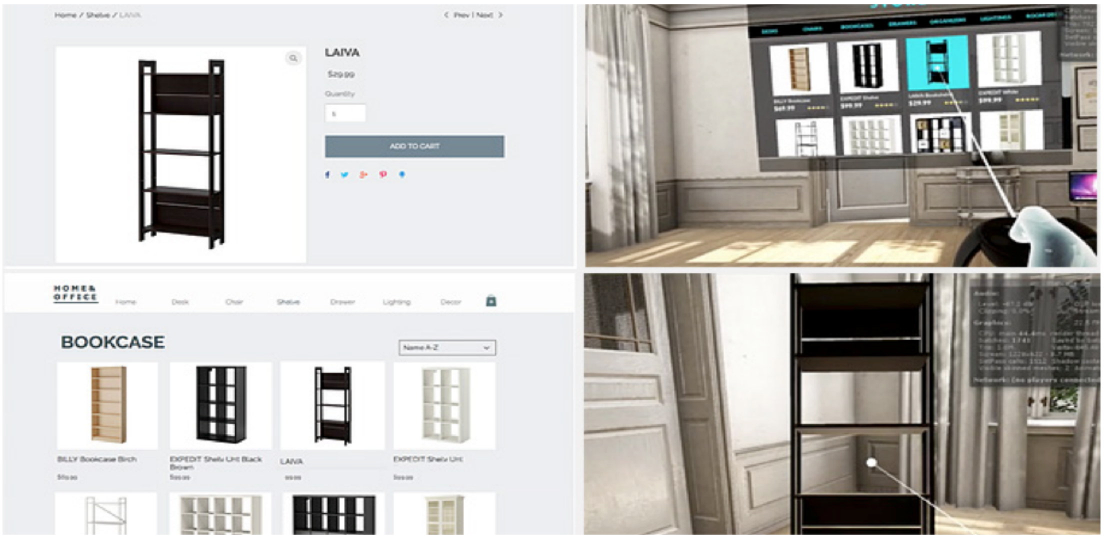


Figure 3.1. The result of the pilot study: presenting the same speaker with the 360 product viewer significantly enhance the choice of the hedonically superior option

and involvement with the product were controlled as covariates since females are generally known to show a higher preference for hedonic products and participants' involvement with the speaker could potentially have influenced the choice. The ANCOVA results showed a significant difference between those who experienced the 2D website and the 3D interactive product viewer in their choice as shown in Figure 3.1. (M_{3D}= 40.4%, M_{2D} = 24.0%, F (1, 94) = 4.173, $p < .05$). The results of the pilot supported our hypotheses on the interplay between shopping environments and a product choice.

4. METHODOLOGY

This section describes the methodology used in Study 1. In this study, I conducted a preliminary investigation to examine the impact of presenting products in a 3D VR environment on consumer choice. I created a fictitious 2D website and a 3D VR store that carry the same set of



2D website 3D VR store

Figure 3.2. The screenshot of a 2D website and example scene from the 3D VR interaction

products, both hedonic and utilitarian goods. Hedonic products were generally more visually appealing, luxurious and expensive than utilitarian products. To tap into more realistic shopping scenario, I included 91 top-selling home office products from online retail stores and examined how participants make different choices across the shopping environments. For 2D shopping experiences, I presented the conventional static 2D website on computer screens. For 3D shopping simulation, I used a fully immersive virtual reality (VR) head-mounted display to deliver a compelling and dynamic 3D virtual environment. The same group of research participants was asked to shop with a 2D website and a 3D VR store interchangeably and I recorded the share of hedonic products amongst their selections. In order to examine consumers' opinion on VR stores, the follow-up interview was conducted after the experiment.

4.1. Virtual Store Design

Two versions of shopping interfaces were constructed: a 2D website and a 3D virtual reality store. The 2D website was developed using HTML, CSS, and Javascript. To enhance the

Figure 3.3. The examples of product categorized as utilitarian and hedonic products
* Product pretest results (0 = "utilitarian" and 10 = "totally hedonic")

similarity of experiment setting to real shopping experiences, I selected one of the top online retailers and mimicked its website design. All the products were presented with still images. The 3D VR interface was developed using Unity3D. In the 3D VR condition, the products were presented as life-size 3D models. The same website was displayed within a 3D VR environment so that users could easily navigate and search for goods. As they click the image of the product, they could view the 3D models and interact with them with their virtual hands. The VR experience was run using an Oculus Rift CV1 and Oculus Touch controllers (Figure 3.2).

4.2. Product pretest

Our mock shopping interfaces featured 91 home office products. In a pilot test, participants indicated that this was an appropriate amount of products to simulate realistic shopping interface. I conducted a product pretest to assess hedonic attributes of these products. Thirty-three independents raters who were not informed of the study goal were recruited from a crowdsourcing online survey tool, Amazon Mechanical Turk (54% female, average age: 32.54; SD = 7.98). They reviewed all home office goods and rated products as hedonic or utilitarian on a scale (0 = "totally utilitarian" and 10 = "totally hedonic"). The definitions of hedonic and utilitarian were provided. If the mean value was higher than 5, the product was coded as the hedonic item. 52 percent of the products were coded as hedonic products. The average price level of hedonic products was $92.24 and the average price level of utilitarian products was $58.99.

4.3. Participants and Procedure

Participants were recruited through flyers in the University campus. Participants were comprised of 40 college students (21 Female). The age of participants ranged from 18 to 44 years (*M* = 21.5, *SD* = 4.3). The college students fall into a major target group for the VR industry (Perkins Coie, 2018; Deloitte, 2018), thus can appropriately represent the target market for VR shopping applications. Three participants were removed from data analyses due to a recording error. First, the participants were given with written instruction for the study procedure and then browsed the 2D website on the computer screens. They were encouraged to browse the site for as long as they wanted and choose the products they would like to buy. After the completion of this stage, participants were introduced to the 3D VR interface, which allowed virtual interaction with life-sized 3D products. Participants were asked to choose the particular products that they would like to purchase. During this process, participants' behavioral data in each shopping conditions (i.e. the number of products participant selected, the total price of the products, choice of hedonic products) was recorded. After experiencing both stores, participants filled out a questionnaire on their demographic information. Next, they were invited for the follow-up interview. The interview

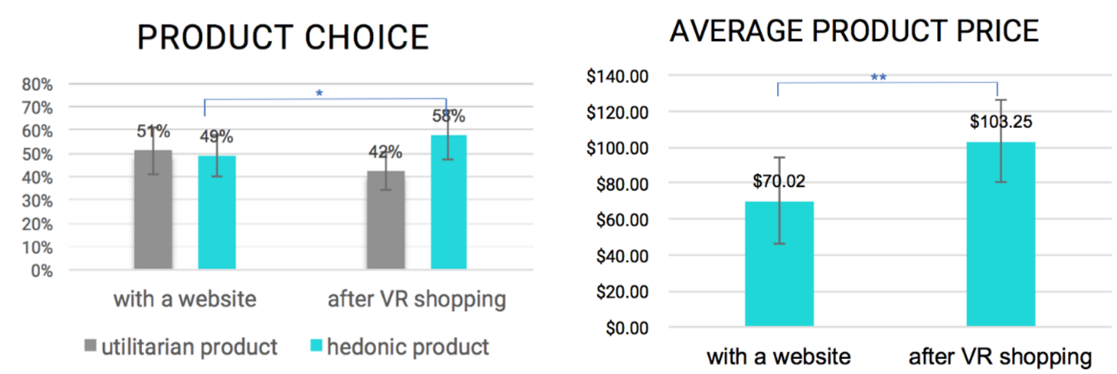


Figure 3.4. The result of study 1: The chance of choosing hedonically superior options increased significantly after the participant used VR store. * indicates p <.05, ** indicates p < .01 *** indicates p <.001

questionnaire include: 1) How would you describe your shopping experience in VR? 2) What is the major difference compared to online shopping? 3) Will you use VR for shopping? 4) What are the factors that influence whether you use VR for shopping? The entire process took approximately 30 to 45 minutes. Participants were compensated with five-dollar at the completion of the study participation. The study protocol was reviewed and approved by the Institutional Review Board at the University of Wisconsin-Madison.

5. RESULTS

5.1. Impact of shopping environment on product choice

73.3% of participants chose different items after they used a VR store. Participants spent a significantly longer time in VR shopping environment (M = 17.31, SD = 4.21) than with the website (M = 7.42, SD = 2.34). I measured and compared the share of hedonic products in each shopping condition. The percentage of hedonic products in total selection was calculated. The results of ANOVA indicated a statistically significant difference between the website and the VR condition. Participants final selection include more hedonic products after they used VR compared to their original selection with a website (M_{website}= 48.83%, M_{VR}=57.63%, F (1, 38) = -4.33, p

< .05). Accordingly, the average price for the selected product significantly increased after they shopped with VR ($M_{website}$= \$70.02, M_{VR}=\$103.25, F (1, 38) = -2.44, $p < .001$). The results of the study are presented in Fig. 3.4. Overall, the results provide further support for hypothesis 1 and hypothesis 2. As predicted, that presenting product using immersive 3D VR interface significantly enhance the chance of choosing hedonically superior products.

5.2. Follow-up Interview: Shopping Experience with VR

In this follow-up interviews, participants were asked to compare VR shopping on conventional online shopping and describe their opinions on the relative benefits of VR shopping. All interviewees mentioned the informativeness of VR store. Participants often described VR shopping as an informative medium that can help them to understand the products' size and fit. Interviewees frequently use terms such as "informative" and "helpful" to illustrate their shopping experience with VR. Participants generally hold a positive attitude toward VR shopping because of additional information VR shopping can provide. Three participants shared their recent experience of online furniture shopping and indicated their willingness to use VR in the future because seeing the real-scale product would have greatly helped them to have a sense of how big the furniture piece is. Five participants said the major benefit of using VR is being able to see how well different objects would go together.

Another frequently mentioned benefit is an enjoyable experience. One participant said even if he would not use VR store to purchase the product, he is willing to use it in the future as a means to have an enjoyable and fun experience. One-fourth of participant spent a long time with VR—longer than 30 min—as they find it genuinely fun and playful to interact with life-scale virtual objects in the virtual worlds. Table 3.2. Shows sample verbatims for perceived benefits of VR shopping and interviewees' experience with VR.

Table 3.2. Perceived Benefits of the use of VR store	
Perceived Benefits	Sample Verbatims
Informativeness	"Shopping in virtual reality was definitely helpful to figure out the size and how different products work together." "I would say virtual shopping is informative." "It helps me with size and stuff. It would make shopping a lot easier." "My house is pretty small. So whenever I buy things, I have to be aware of exactly how things will fit. So I think if there is a way that I could actually have my own place represented in VR, it will be a lot more helpful." "If you are in the store with a different bunch of items, you don't know what would it look like together." "Sometimes I buy a chair in the store and I take it home and it is way too big."
Playfulness	"I didn't realize it's already been an hour. It was really fun." "It was fun and definitely entertaining" "It feels like I was transporting to the new world." "You put on a headset and it's a whole different world." "I don't know if I would actually use it for shopping, it was probably more of game."

6. DISCUSSION

Virtual reality is gaining prominence in the e-commerce industry, however, little is known on how the use of VR would influence the consumer decision-making process. In this exploratory study, I compared the VR store to a conventional website and examined how consumer product choice varies depending on the shopping modality the shopper use. In order to better understand the relative merits of VR, I conducted follow-up interviews and further examined the perceived benefits of VR shopping.

In regard to the product choice, I posit that VR can be effective shopping means especially for visually appealing hedonic goods. Drawing upon Hammond's cognitive continuum theory (1988), I proposed that an interactive 3D virtual environment would induce intuitive thinking and lead consumers to choose visually more appealing and luxurious hedonic products, whereas the website with still images and text would induce analytic thinking and increase the chance of choosing a more utilitarian product. The results of the comparative study supported the prediction.

When shopping with VR, the likelihood to choose more expensive and visually appealing furniture over less expensive and utilitarian furniture increased significantly.

In addition to examining participants' product choice, I also conducted follow-up interviews to better understand users' shopping experience with the VR store and identify its relative merits over conventional online websites. The follow-up interview reveals that two major benefits of VR shopping are: its informativeness and enjoyable experience VR provides. Interviewees frequently addressed that being able to see products' life-scale size, as well as examining the product in the context of use, were especially beneficial for shopping furniture online.

The results of this study can provide meaningful managerial implications for online retailers. Despite the rapid growth of e-commerce sales, large-scale luxury and designers goods represent one of the toughest product segment to sell online. This study finding suggests that virtual reality display can be particularly beneficial for such goods. From a consumer's point of view, an interactive 3D product representation allows consumers to better appreciate visual aesthetics and enjoyable features of the product, thus providing a wealth of information that is essential for making choice for hedonic goods. From a practical point of view, this study findings on the interplay between a product feature and information display provide a useful guideline for implementing a new virtual reality marketplace.

STUDY 2 The Roles of Informativeness and Playfulness

How 3D virtual reality store can shape consumer purchase decision

1. INTRODUCTION

This study builds on earlier Study 1 that examined the impacts and benefits of VR shopping. The results of Study 1 provide two meaningful insights: first, shopping with the virtual reality environment may allow users to better appreciate hedonic aspects of the product, thereby may increase the chance of choosing hedonically superior products over utilitarian options; second, there are two major perceived benefits of the virtual reality store namely informativeness and playfulness of the VR store. The result of study 1 indicates that VR may be especially an effective shopping means for hedonic products, yet it doesn't fully address why consumers prefer the hedonically superior option when using the VR store. Based on the findings from Study 1, I posit that two major perceived benefits of VR shopping—informativeness and playfulness—will provide explanatory power for the underlying causes of consumers' preference for the hedonic product in VR.

The aim of this study is twofold: (1) to explore how critical interface features of VR—interactivity, visual-spatial cues, and graphics quality—work together to influence perceived informativeness and playfulness; and (2) to examine the interplay between informativeness and playfulness and its impact on consumer purchase decision making. In setting out these two goals, I use the term "informativeness" to refer to the richness of product-related knowledge or information the shopping interface provides, and the term "playfulness" to refer to the enjoyable and recreational experience provided by the shopping interface.

I propose that playfulness and informativeness produce different relative impacts on different stages of the purchase decision-making process: *product evaluation* and final *purchase* *intention*. More specifically, I posit that experiencing a playful interface will lead consumers to place more weights on hedonic attributes of the product (e.g. stylish design) as a key consideration factor in the evaluation stage, whereas informativeness is potentially a more important explanatory variable for subsequent purchase intentions. I tested varying effects of informativeness and playfulness using different forms of 3D and 2D virtual interfaces.

This study differs from previous research in two significant ways. First, although the role of informativeness and playfulness in online consumer behavior has been a fertile research topic, a dominant emphasis in much of the prior research has been on the impact of informativeness and playfulness on consumers' technology acceptance (e.g., Kim & Forsythe, 2008; Ha & Stoel, 2009). This study instead examines the consumer purchase decision-making process. I distinguish the "product evaluation" from the "purchase intention" and examine how informativeness and playfulness influence these two processes differently.

Second, many prior studies predominantly focused on the structural relationship between variables, thus they tend to analyze consumer responses based solely on one single stimulus (e.g., Kim & Forsythe, 2008; Pantano & Servidio, 2012). The contribution of this study lies in creating variations of interface features. The question of how diverse interface features that distinguish 3D VR from conventional 2D medium—interactivity, visual-spatial cues, and graphics quality—would work together to influence the perceived level of informativeness, playfulness and subsequent consumer purchase decision-making process remains unexplored.

2. RELATED WORKS

2.1. Perceived playfulness

Playfulness has been a popular research topic in marketing literature in the past few decades, usually as a precursor of flow state (Novak, Hoffman & Yung, 2000; Mathwick, Malhotra, & Rigdon, 2001). However, it is not clear how to define “playfulness,” whether it denotes playful design elements of a shopping environment or individual traits and motivational characteristics that seek pleasure (Berlyne 1969; Lin, Wu, & Tsai, 2004). In the presented study, I consider “perceived playfulness” as an experiential outcome of shopping that provides enjoyment and escapism; in other words, the degree to which a shopping environment transforms shopping activity into a recreational and playful experience.

The conceptualization of playfulness in this study is based on the prior work of Mathwick and Rigon (2004), where they characterized “perceived play” as a concept that reflects two dimensions; intrinsic enjoyment and escapism. Both dimensions are central in portraying experience with virtual reality. The enjoyment aspects of virtual reality are well-documented, in that people tend to feel great enjoyment when they are experiencing an immersive and compelling virtual environment (Sylaiou, Mania, Karoulis, & White, 2010; Yim et al., 2017). The escapism dimensions of perceived playfulness reflect a state of psychological immersion that allows shoppers to temporarily “get away from it all” (Huizingh, 2000; Mathwick, Malhotra, & Rigdon, 2001). An immersive VR environment particularly excels at delivering a sense of escapism for its very nature, as it surrounds users with a simulated virtual environment and isolates them from the physical world (Steure, 1992). Thus, I consider “perceived playfulness” as a stimulus-driven perception, a shopping environment that provides enjoyment, entertainment, and escapism to perceivers. I use the term playfulness instead of enjoyment, another popular term that describes the experiential aspects of shopping, to better reflect the interface-related features of shopping. Unlike the playfulness construct, enjoyment often refers to an individual’s current emotional state rather than the experiential outcome of computer use that “playfulness” presumably entails (Goetz, Frenzel, Pekrun, & Hall, 2006).

It is important to note that the definition of playfulness in this study focuses on general pleasurable experiences and not on specific playful design elements. Because "playfulness" as a term saw widespread adoption in computer game research (Deterding, Dixon, Khaled, & Nacke, 2011), a handful number of marketing studies adopt the term and use it to refer to gameful elements of the virtual interface(Ha & James, 1998). For instance, Ha and James (1998) defined playfulness as a subconstruct of interactivity, specifically referring to interaction design features such as games on websites. However, such a narrow definition of playfulness would be limiting and may not capture the locus of shopping in virtual reality. Discussing "perceived play," Mathwich and Rigon (2004) argue that even a seemingly goal-driven task, such as searching for information on the web, can also be recreational and playful when users are highly focused and engaged in a searching activity. Given the immersive nature of virtual reality (Slater, 2003), a realistic and compelling virtual environment can be playful and entertaining even with the absence of particular game elements.

2.2. Perceived informativeness

Informativeness is another important dimension of the virtual reality shopping experience. The promise of being able to provide additional product information has been a major driver for the commercial deployment of VR in marketing applications (Guttentag, 2010). Prior research acknowledges that the marketing potential of VR lies in its ability to provide extensive sensory information to prospective online customers (Sussmann & Vanhegan, 2000; Kim & Forsythe, 2008; Suh & Lee, 2005). A stereoscopic display of VR HMDs is capable of conveying depth to viewers, which helps consumers figure out the size and fit of the product. More direct interaction with the 3D product, even by merely rotating the object with a computer mouse, is known to mitigate the perceived risk of online shopping (Suh & Lee, 2005; Li, Daugherty & Biocca 2008). A body of literature has explored informativeness as a source of decision control that supports the successful completion of a shopping goal, ultimately giving confidence to consumers (Gallino & Moreno, 2018; K. Ran & Itamar, 2000). Based on such a conceptualization, we define informativeness as the perceived richness of information or product-related knowledge provided by the shopping interface that can enhance a consumer's confidence.

3. Hypotheses Development

3.1. Determinants of playfulness and informativeness

Playfulness and informativeness are not inherent properties of media but vary widely depending on both the interface design and the perceiver (Heeter, 2000). Therefore, claims that VR is naturally more informative and playful than a still image may not hold. Marketing research findings on VR, for instance, often contradict a popular belief that interactions with a life-size 3D product would be informative. Consumers do not necessarily find the 3D VR format more informative than a conventional 2D medium, quoting the unrealistic graphic representation the main reason (Kim & Forsythe, 2008). In order to address these conflicting claims and research findings, we focus on three major interface design features in the present study: interactivity (direct product interaction), visual-spatial cues (visualization of the spatial information with stereoscopic display), and graphics quality. I further examine how each of these three major interface features informs playfulness and informativeness.

Interactivity

Interactivity can enhance the level of perceived informativeness by providing the means for closer inspection, allowing a user to selectively process information and focus on necessary details (Liu & Shrum, 2009). Studies found that an interaction that enables shoppers to freely rotate and place the product significantly enhances a consumer's perceived level of product knowledge (Suh & Lee, 2005; Li, Daugherty & Biocca 2008).

Interactivity is also closely linked with playfulness. An interaction that enables the user to virtually simulate diverse scenarios, such as placing multiple products, together can enhance the level of the perceived playfulness of the virtual shopping experience (Kim & Forsythe, 2008). A high level of interactivity is known to promote a sense of being in control, which serves as a precondition for consumers to immerse themselves in virtual shopping (Ward & Barnes, 2001). Studies suggest that control over the virtual environment is associated with an optimal flow state, where users achieve a sense of self-efficacy and psychological immersion, which are critical elements for the development of playfulness (Csikszentmihalyi, 1997; Mathwick & Rigdon, 2004; Novak, Hoffman, & Yung, 2000). Therefore, I expect a high level of interactivity in 3D product visualization can enhance the levels of perceived informativeness and playfulness.

H1a. A high level of interactivity will result in an increase in perceived informativeness.

H1b. A high level of interactivity will result in an increase in perceived playfulness.

Visual-spatial cues

Visual-spatial cues are another critical element, especially for the product whose size and contextual fits are crucial for product assessment (e.g. furniture, home electronics). Cognitive psychologists define visual-spatial cues as visual inputs that guide people to construct the object's spatial relations (Held & Durlach, 1991). When people are presented with two-dimensional displays, such as a desktop screen, they construct the mental representation of the environment by translating the 2D representation to 3D information (Essen, Andelson, & Felleman, 1992; Regian, Shelbilske, & Monk, 1992). Virtual Reality displays eliminate such needs. A stereoscopic display of VR enables users to process visual-spatial information by placing them in a life-size 3D immersive environment.

H2. The presence of visual-spatial cues in the 3D stereoscopic display will result in an increase in perceived informativeness.

Graphic-Quality

The graphics quality of a represented product is another factor that contributes to informativeness. Unfortunately, many current commercial 3D shopping applications offer low graphics quality because 3D modeling programs commonly used in generating the imagery remain difficult to use. Unlike photographs and video, creating a 3D object from scratch requires the skills of an experienced designer and is relatively more difficult to capture for a real-world object. The recent advances in 3D laser scanning and photogrammetry technology that extracts 3D data from 2D photographs enable the possibility to create photo-realistic 3D objects more effectively (Baltsavias, 1999; Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012). In the presented study, I use photogrammetry to produce highly detailed graphic representations of 3D products. A highly detailed and realistic environment can also enhance the perceived level of playfulness. Computer displays that deliver more vivid and realistic visual imagery generally create a strong illusion of being in the real world (Slater & Wilbur, 1997). Such a strong sense of presence in a virtual world results in psychological immersions and a sense of escapism, which are essential dimensions of playfulness (Mathwick & Rigon, 2004).

H3a. Highly detailed graphics representations will result in an increase in perceived informativeness.

H3b. Highly detailed graphics representations will result in an increase in perceived playfulness.

3.2. Impacts on the Consumer Purchase Decision-Making Process

Consumer Decision-Making: Evaluation and Purchase Intention

Consumers go through a number of stages before making a final purchase decision (Engel, Blackwell, & Kollat, 1968; Kotler, 2003). In consumer decision-making journey, "evaluation" is described as a stage when consumers evaluate different sets of alternatives on the basis of varying product attributes and examine whether these products could potentially fulfill their needs (Gupta & Harris, 2010), and "purchase" as the penultimate stage where a final transaction occurs (Kotler, 2003). In the presented study, I examine *product evaluation* and *purchase intention* as two different processes; the former refers to a stage where consumers evaluate different sets of products and form a preference for a particular product over others and the latter refers to a final stage where a consumer indicates their willingness to proceed to purchase. I expect that two different dimensions of a shopping interface—informativeness and playfulness—would influence each stage in distinctive ways.

Moment of Impulse: Playfulness and Hedonic Product Attributes

Consumers evaluate different products and form an initial consideration set based on their impression and perception of the products (Hauser, 2014; Kotler, 2003). When they encounter a product that is hedonically superior, consumers are more likely to engage in impulsive behavior (Rook, 1987). Consistent with previous research in marketing, I use the term "hedonic attributes" to refer to fun, pleasure, and enjoyment related to the projected benefit the consumption offers (Batra & Ahtola, 1991; Khan, Dhar, & Wertenbroch, 2004). In the context of furniture shopping, for example, the appeal of attractive style and luxurious design are hedonic attributes.

There is converging evidence that shows a positive link between the preference of hedonic goods and an immersive virtual shopping interface (Roggeveen, Grewal, & Townsend 2015; Shen, Zhan, & Krishna 2016). The recent work of Roggeveen, Grewal, and Townsend (2015) suggests that the use of dynamic visuals increases the influence of hedonic attributes on product evaluation, making hedonic benefits more salient in product evaluation than when the same set of the products are presented with static imagery. Similarly, Shen, Zhan, and Krishna (2016) showed that more direct interaction with a product evokes sensory and affective responses and hence increases the salience of hedonic benefits. A theoretical rationale these prior studies provide are draw upon research on construal level and mental imagery (Trope & Liberman, 2010). Construal-level research has noted that consumers tend to prefer hedonic product attributes at a low psychological distance, in other words, when an event is likely to take place immediately than farther into the future (Polman, 2012). Because an immersive virtual reality environment helps shoppers to feel as if they are experiencing the product, it can enhance consumers' engagement and thus helps people to easily elaborate or imagine how much they will enjoy the product (Shiv & Huber, 2000; Roggeveen, Grewal, & Townsend 2015). Given the strong link between immersion, escapism and a playful shopping interface (Mathwick & Rigon, 2004), I posit that hedonic attributes will be weighed more heavily when a virtual interface is perceived to be playful.

H4: A playful shopping experience will increase the preference for hedonic product attributes.

Buying with Reasoning: Informativeness and Purchase Intention

The affective-cognition model suggests that when the tasks demand more cognitive processing resources, a decision is likely to be based more on cognitive reasoning than on spontaneously evoked emotion (Shiv & Fedorikhin, 1999). In the online shopping context, consumers are less committed when they are examining products for their initial consideration set, whereas a purchase decision generally involves more dedication and a greater level of cognitive involvement in decision making (Wolfinbarger & Gilly, 2004).

Because a purchase decision demands actual monetary resource allocation, decision-makers search for reasons and arguments to justify their spending (Griffin & Tversky, 1992). Informativeness is a key consideration in such a decision task, as it helps to provide justifiable arguments and reduce perceived risks of online shopping (Luo, 2002). To the extent that the consumer is confident in the information provided to them, the likelihood to proceed to purchase should, therefore, be enhanced.

In summary, I posit that informativeness and playfulness influence the purchase decision-making process in two distinct ways. Unlike playfulness that spontaneously induces affective responses, informativeness does not necessarily evoke enjoyment and excitement. Instead, informativeness is more directly related to the perceived risk of online shopping. As such, the final purchase decision is likely to be made based on a cognitively driven analytic process to reduce the probability of monetary loss, while preference for the certain product is more likely to be influenced by an automatically evoked-affective response. Thus, I propose that playfulness and informativeness produce different relative impacts on product evaluation and subsequent purchase decision stages. More specifically, a playful shopping experience may enhance the relative valuation of hedonic attributes when consumers form an initial consideration set, yet such preference for hedonic attributes would not lead to subsequent purchase intention if the virtual interface does not provide sufficient level of information. In other words, if a virtual interface is perceived to be merely playful yet not informative, the preference for hedonic attributes would not likely lead to subsequent purchase intention. On the other hand, if a virtual interface is highly playful and highly informative, preference for visually appealing and luxurious hedonic product attributes would likely translate into subsequent purchase intention.

H 5: Perceived informativeness will be a stronger predictor of subsequent purchase intention than perceived playfulness.

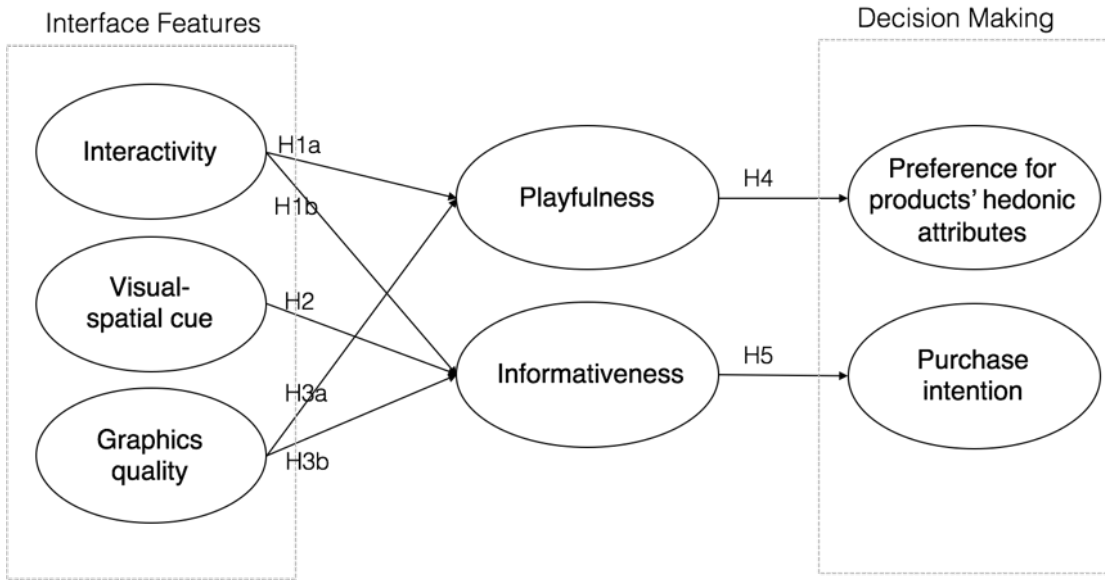


Figure 4.1. Proposed conceptual framework: The distinctive roles of informativeness and playfulness in predicting consumers' preference for products' hedonic attributes and purchase intention

4. METHOD

The first goal of this study is to understand how interface features—visual-spatial cues, graphics quality, and interactivity—influence the perceived level of informativeness and playfulness. I further examine the roles played by informativeness and playfulness in influencing the consumer decision-making process. In order to understand these relationships, I followed Coyle and Thorson's (2001) approach and created fictitious virtual shopping interfaces by operating each interface feature.

This study was conducted within the context of office furniture goods—an office desk and chair—for three reasons. First, Suh and Lee (2005) observed that the effect of using 3D VR is greatest for furniture because salient attributes of the furniture product (e.g., size and fit) corresponds to the strength of the 3D virtual interface. Second, the furniture industry is the major segment that has eagerly incorporated 3D VR into a commercial strategy (Perkins Coie, 2018).

Large retailers like Macy's and Walmart have jumped on the bandwagon of VR for furniture shopping. Third, office furniture provides both utilitarian (e.g., durability, ergonomic) and hedonic benefits (e.g. style and luxurious appeal), hence fits well for the objective of the study.

4.1. Virtual Store Design

In order to examine the effects of the aforementioned three interface features, I adopted both a 2D medium and 3D VR for a comparison study. To examine the impact of *interactivity*, I created a conventional 2D website that displays the product with still images and videos, two most popular means for online product presentation (Roggeveen, Grewal, & Townsend 2015), with which users have limited interaction with the product. To examine the role of *visual-spatial cues*, I created a 3D web environment where products are presented in a 3D virtual room but displayed on the desktop computer screen instead of stereoscopic 3D VR displays. The *graphics quality* of the products was operated using photogrammetry technology, image processing technology that

Table 4.1. Versions of virtual shopping interface

		Operations		
v	The main presentation mode	Visual-spatial cue	Graphics quality	Interactivity
1	Still image	Desktop display	Low detail	Low
2	Still image	Desktop display	High detail	Low
3	Video	Desktop display	Low detail	Low
4	Video	Desktop display	High detail	Low
5	Interactive 3D viewer	Desktop display	Low detail	High
6	Interactive 3D viewer	Desktop display	High detail	High
7	3D VR HMDs	Stereoscopic display	Low detail	High
8	3D VR HMDs	Stereoscopic display	High detail	High

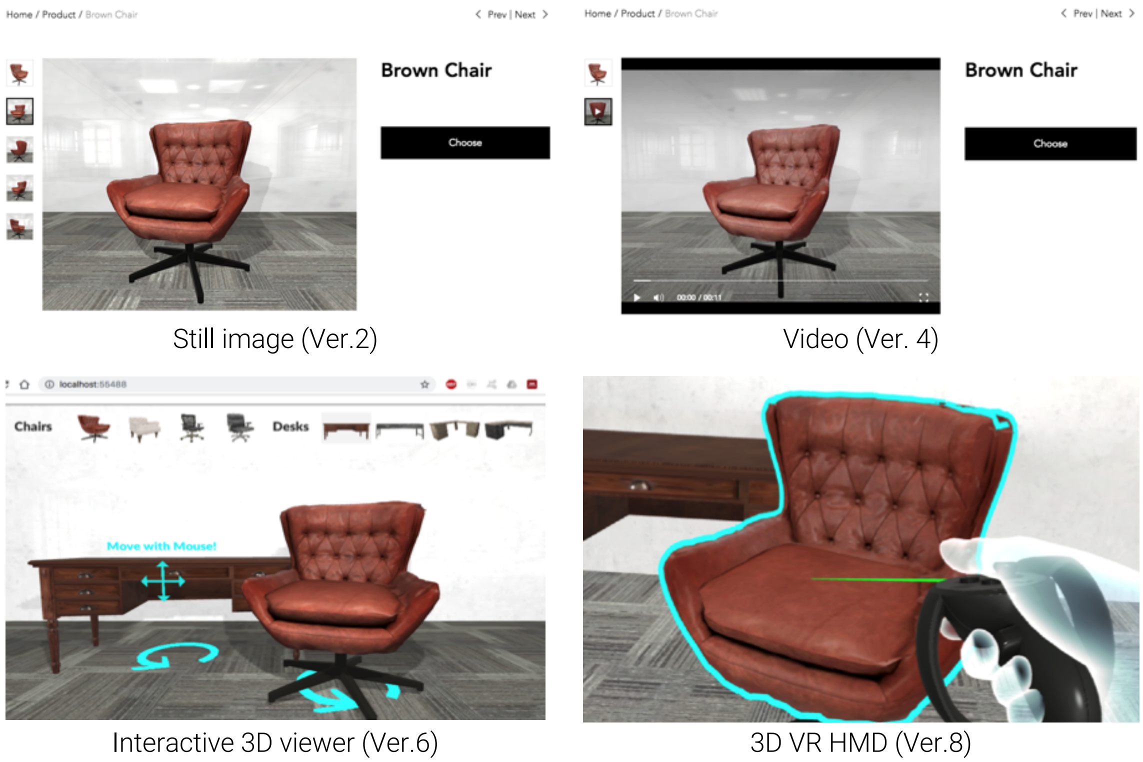


Figure 4.2. Examples of interfaces

reconstructs 3D objects from digital photographs by extracting the position of surface points through computer-vision algorithms (Baltsavias, 1999).

Photogrammetry can capture the accurate dimensions of the real object and reproduce a high-resolution 3D model with a greater level of detail than is available with conventional 3D modeling (Westoby et al., 2012). For 3D conditions, products were represented in two different modes (low graphics details vs. high graphic details). As a result, eight versions of virtual shopping interfaces were created as seen in Table 4.1.

To tap into realistic shopping scenarios, I included the top-selling office furniture of major furniture retailers and prepared 4 different options for desks and chairs respectively (see Appendix). We carefully choose options that vary in design and style within a similar price range. The same set of products was presented across eight virtual interfaces. In a still image condition,

Figure 4.3. High graphic detail (left) and low graphics detail (right)

the products are displayed with 5 images taken from different angles. The video condition presents the same set of the products in the form of film clips which show the rotating product in a steady motion. For 3D web conditions, we displayed the 3D virtual room where users could virtually place and interact with the product using a computer mouse. Because users are presented with a virtual room, it is possible that the surrounding room environment may influence a choice. For example, consumers may choose a product that goes well with the wall paint color. In order to avoid such a possibility, I presented the same room environment, neutral in design style, across all eight experimental conditions. The images and video of the products are taken in the same room environment as seen in Figure 4.2. For the VR condition, the same 3D virtual room is presented with head-mounted displays. Users could freely place and rotate the products using a controller and joystick. The VR experience was run using an Oculus Rift CV1 and Oculus Touch controllers.

4.2. Participants and Procedures

A prior G*Power analysis for the eight experimental conditions ANOVA between factors design suggested that the desired sample size was 192 with the effect size of 0.25, a power of 0.90 at an alpha level of 0.05 (Faul, Erdfelder, Lang, & Buchner, 2007). To ensure participants are equally distributed across 8 conditions, 224 participants are recruited (28 participants per each condition). After eliminating uncompleted responses, 218 responses were used for the final data analysis. Because the target product in this study is furniture, I aimed to recruit young adults who typically fall into the target consumer segment for furniture retailers. The latest Consumer Reports shows that millennials are currently the largest consumer group in the U.S. furniture and home goods markets (Consumer Reports, 2018). In order to effectively recruit normative samples of millennials, we used two recruitment strategies: online recruitment with Amazon Mechanical Turk and local recruitment in a Midwestern city.

Amazon Mechanical Turk (MTurk) is a crowdsourcing tool that allows a requester to recruit a specific population. The average age of Mturk workers is roughly 32 years old, which meets the target age of our recruitment criteria (Mason & Suri, 2012). In order to recruit more representative middle-class U.S. consumers, I used a premium qualification service provided by Mturk and recruited participants with two inclusion criteria: 1) U.S. residents and 2) average household incomes of $25,000 to $50,000 and $50,000 to $75,000. 169 participants were recruited from Amazon Mechanical Turk (Mturk) for virtual interface conditions where users could use a desktop to participate in the study (version 1-6). Participants were randomly assigned to one of the research conditions.

For the VR format conditions (version 7-8), 49 participants were recruited locally in a Midwestern town and randomly assigned to one of two VR interface conditions. I posted an online ad at Craigslist and in social media, and also recruited participants through a University outreach program. No participants had prior experience with virtual reality. In order to avoid potential confounding effects, I carefully recruited local participants to match the Mturk population in terms of gender and age ratios. Chi-Square analysis indicated that participants' gender (χ^2 (1,217) =.047,

p =.484), age (χ^2 (5,217) =3.912, p =.562), education (χ^2 (4,217) =5.267, p =.261), and household income level (χ^2 (5,216) =8.321, p =.139) did not differ significantly across experimental groups.

Participants were given brief instructions prior to the study and reviewed a scenario about moving to a new office. The same set of four desks and four chairs were displayed to the participants across all experimental conditions. They were encouraged to examine products as long as they desired before choosing one particular item they like amongst the four options. After they chose one desk and one chair, I prompted the questions, asking the importance of hedonic benefits when they chose the products as an initial consideration set and their willingness to proceed to purchase. They then proceeded to the rest of the questionnaire. The study protocol was reviewed and approved by the Institutional Review Board at the university.

4.3. Measurement Items

The full list of measurement items is available in Table 2. I used the adjusted self-reported questionnaire taken from prior literature. The dependent variables included perceived informativeness, playfulness, valuation of hedonic benefits, and purchase intention. The questionnaire item for the preference of hedonic attributes was measured on seven numeric rating scales, where 1 indicates “unimportant” and 7 indicates “important” as decision criteria when respondents choose one product among different options. The rest of the questionnaire was measured on a seven-point Likert scale where 1 indicates their strong disagreement and 7 indicates strong agreement with the statement.

I also included questionnaire items for four control variables: product involvement, attention, ease of use, and the individual’s hedonic orientation. The questionnaire for these items are presented in table 4.2. The participant’s involvement with the furniture was measured as a control variable since their general interest in furniture could potentially influence their choice and purchase intention. Attention was also measured as a control variable. The study on the 3D stereoscopic display and consumer responses show the strong link between media novelty with attention (Yim, Cicchirillo, & Drumwright, 2012; Yim, Chu, & Sauer, 2017). In order to examine the possibility that the novelty of virtual reality made people pay more attention to choosing a product, we included attention as a control variable. Perceived ease of use and the individual's hedonic orientation, traits that seek pleasurable shopping experiences and stylish product design, are also measured as control variables.

Cronbach's Alpha was used to assess reliability for all measurement constructs (Table 4.2). Two constructs, hedonic attributes, and product involvement were slightly below the recommended criterion of 0.7 (Barclay & Smith, 1995; see Table 4.2 for all Cronbach's Alpha). However, I decided to use these measurement items instead of dropping them for the following reasons. In the case of hedonic benefit, previous studies often used an uni-scale, only "Style and attractiveness" (Chitturi et al, 2008); however, this one single scale may not be sufficient to capture the hedonic dimensions of furniture products. Unlike other popular study subjects such as computers and cars, style and attractiveness are evidently an important decision criterion for furniture (Lee & Suh, 2009). Thus, we decide to include an item "luxurious appeal" despite its low alpha value given its strong conceptual link to hedonic benefits. In the case of product involvement, both measurement items — the importance of products ("buying a right desk and chair is very important to me") and individual's scrutiny ("I would compare different brands very carefully") — can influence participants' engagement with furniture shopping. Because these items were control variables and both of them can potentially influence the study results, I included these two in further data analysis.

Table 4.2. Construct and Measurement Items

Construct		Measurement Items	Cronbach's α
Manipulation check variables	Visual-spatial cue (Held et al, 1991)	1. The XYZ interface visualizes the product's life-size scale. 2. I could figure out a product's accurate size and fit with this	.853
	Graphics quality (Babin & Burns, 1998)	1. The graphics quality of the products was clear and sharp. 2. The products looked photo-realistic. 3. The products looked realistic.	.900
	Interactivity (Coyle & Thorson, 2001)	1. I was able to freely rotate the product and examine it from different angles. 2. I was able to freely place the product in the 3D virtual room. 3. The XYZ interface was highly interactive.	.935
Dependent variables	Perceived informativeness (Jiang & Chan, 2009)	1. This XYZ interface is informative for furniture shopping. 2. This XYZ interface is helpful for furniture shopping. 3. This XYZ interface is resourceful.	.898
	Perceived playfulness (Mathwick & Rigon, 2004)	1. Shopping with this XYZ interface is enjoyable. 2. Shopping with this XYZ interface is exciting. 3. Shopping with this XYZ interface is fun. 4. Shopping with this XYZ interface makes me feel like I am in another world.	.909
	Hedonic attributes (Chitturi et al, 2008)	Importance of each attribute as decision criteria: 1. Style and visual attractiveness 2. Luxurious appeal	.611
	Purchase Intention (Chang & Wildt, 1994)	1. I would like to order the product I chose. 2. I would like to purchase these products in the near future. 3. I will purchase the products I choose the next time I need a chair and a desk.	.878
Control variables	Product involvement (Zaichkowsky, 1985)	1. Buying the right desk and chair is very important to me. 2. If I am purchasing a desk and chair, I would compare different brands very carefully.	.640
	Ease of use (Venkatesh, 2000)	1. This XYZ interface was easy to use. 2. I could easily navigate and search for the product.	.856
	Individual's hedonic orientation	1. In general, shopping for a new product is a recreational activity for me. 2. I enjoy looking for a stylish visually attractive product when I shop. 3. In general, product design is one of the most important decision criteria when I buy a new product.	.701
	Attention (Chandon et al., 2009)	1. When I was choosing a desk and chair, I carefully examine its design and style. 2. When I was choosing a desk and chair, I paid a lot of attention to make the right choice.	.786

5. RESULTS

5.1. Manipulation Check and Control Variables

Prior to testing hypotheses, the manipulation of interactivity, visual-spatial cues, and graphics quality was checked with the survey sample. The analyses of a series of one-way ANOVA revealed significant main effects in the expected directions. Participants exposed to interactive 3D virtual environments were more likely to agree that the interface was highly interactive than those who exposed to the static image and video conditions (F (1, 216) = 141.01, p <.001, η_p^2= .370). Participants exposed to higher graphics quality conditions were more likely to agree that the products looked more realistic than those who were exposed to low graphics quality conditions in overall (F (1, 216) = 13.10, p <.001; η_p^2 = .171); however perceived graphics quality in video conditions (version 3 and 4) did not significantly differ (F (1, 50) = .99, p =.323; η_p^2 = .058). Stereoscopic displays of 3D VR significantly enhanced the understanding of visual-spatial information and helped participants to figure out a product's accurate size compared to desktop display conditions (F (1, 216) = 25.54, p <.001; η_p^2 = .251). These results show that most of the manipulations were successful, except graphics quality manipulation for video conditions.

The table 4.3. presents the descriptive statistic result including the manipulation variables, visual-spatial cues, graphics qualities, interactivity, as well se the dependent measures for this study that includes informativeness, playfulness, hedonic preference, purchase intention. Total time spent for each condition and the attention levels are also reported in table 4.3. 3D VR environments was reported to provide higher level of

Table 4.3. Descriptive statistics: M (SD)										
V	Main mode	Visual-spatial cue	Graphics quality	Interact-ivity	Informative-ness	Playfulness	Hedonic preference	Purchase intention	Time spent	Attention
1	Image	4.56 (1.53)	4.71 (1.29)	4.20 (1.66)	3.81 (1.31)	4.14 (1.45)	4.60 (1.43)	4.14 (1.37)	4.10 (2.40)	5.00 (0.89)
2	Image	4.71 (1.34)	5.46 (1.35)	3.81 (1.56)	4.54 (1.49)	3.82 (1.56)	4.57 (1.91)	4.76 (1.66)	5.40 (3.73)	5.54 (1.15)
3	Video	4.75 (1.51)	4.78 (1.36)	4.11 (1.75)	4.44 (1.47)	4.29 (1.52)	4.95 (1.52)	4.39 (1.31)	3.92 (3.13)	4.97 (0.89)
4	Video	4.60 (1.27)	5.17 (1.42)	4.22 (1.54)	4.58 (1.61)	4.13 (1.40)	4.83 (1.29)	4.77 (1.10)	5.16 (2.08)	5.63 (0.98)
5	3D web	4.80 (1.24)	4.94 (1.45)	5.82 (1.01)	4.97 (1.21)	4.80 (1.22)	5.42 (1.21)	5.11 (1.35)	7.80 (3.95)	5.79 (1.04)
6	3D web	4.87 (1.28)	5.44 (1.20)	6.02 (0.82)	5.48 (0.89)	5.01 (1.39)	5.12 (1.21)	5.20 (1.10)	8.98 (3.83)	5.86 (0.86)
7	3D VR	5.81 (0.70)	4.98 (0.99)	6.21 (0.70)	5.56 (0.85)	6.18 (0.67)	5.28 (1.11)	4.14 (1.01)	11.12 (4.01)	5.30 (0.97)
8	3D VR	5.70 (0.90)	5.84 (0.55)	5.92 (0.95)	5.49 (1.11)	6.26 (0.68)	5.59 (1.10)	4.17 (1.21)	10.09 (3.75)	5.51 (1.00)

informativeness and playfulness than other interfaces such as still images, videos, and interactive 3D web viewers.

4.2. The impact of interface features on perceived informativeness and playfulness

To analyze the impact of interface features on perceived informativeness and playfulness, we first conducted a series analysis of covariate (ANCOVA) and compared means of perceived playfulness and informativeness of different experimental conditions. For example, in order to examine the impact of graphics quality, we compared the conditions where products were presented in lower graphic details (version 1,3,5) to the conditions where products were presented in higher graphics details (version 2,4,6). The results of the ANCOVA are illustrated in Figure 5.

In examining the roles of graphics quality, we expected that respondents would perceive a high graphic quality (version 2,4,6) more informative than low graphics quality environments (version 1,3,5). However, as seen in Figure 5, there were no significant differences regarding perceived informativeness and playfulness between these two conditions (informativeness: F (1, 216) = .37, p =.54, η_p^2= .018; playfulness: F (1, 216) = 1.82, p =.17, η_p^2 = .058). To further examine the impact of graphics quality on informativeness, I compared each set of low and high graphics quality environments (e.g., vers ion 1 and version 2) for three modes of product presentation: image, 3D web, and 3D VR. Video conditions were not included in this analysis since the manipulation of graphics quality was not successful. As seen in Figure 4 (top-left), the impact of graphics quality appears more pronounced in the 3D web and image conditions than in 3D VR. A 3D web environment with higher graphics quality was perceived to be more informative than a 3D web environment with lower graphics quality (M_{ver4} = 4.97; M_{ver5} =5.45; p <.05), whereas a VR environment with higher graphics quality, version 8, was not necessarily more informative than a version 7, a VR with lower graphics quality (p = .659).

While the impact of different graphics quality on informativeness and playfulness was not significant, respondents found interactive 3D interfaces and stereoscopic VR displays significantly more informative and playful than images or video presentation as seen in Figure 4. A series of ANCOVAs also demonstrated the significant impact of interactivity and visual-spatial cue on both informativeness and playfulness.

Multiple regression analysis was employed to test if three interface feature, graphics quality, interactivity, and visual-spatial cues, significantly predicted perceived informativeness and playfulness of shopping interfaces. The result of the regression indicated that three interface features explained a significant portion of the variance in informativeness (R^2 = .56, F (3, 213) =

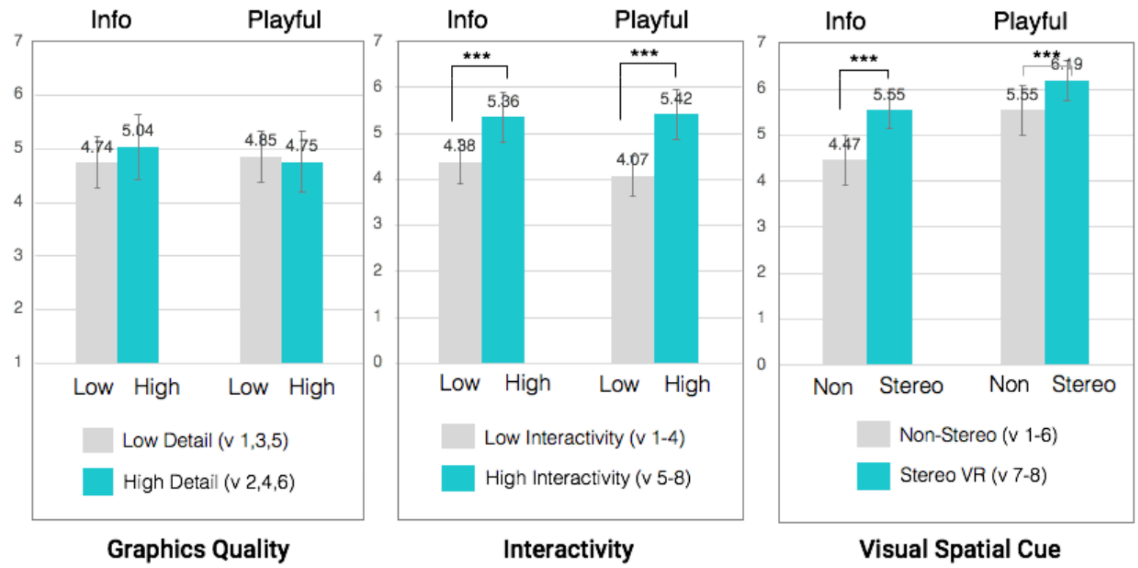


Figure 4.4. Impact of interface features on informativeness and playfulness: In reference to graphics quality, there was no significant differences reported between low graphic quality conditions and high graphic quality conditions for both perceived level of informativeness and playfulness Interactivity and visual spatial other hand had significant impact on informativeness and playfulness. *indicates p <.05, ** p <.01, ** p < .001.

92.12, $p < .001$) and playfulness ($R^2 = .63$, F (3, 213) = 119.50, $p < .001$). All three interface features significantly predicted both perceived informativeness and playfulness.

In summary, regression results showed significant relationships among all three interface features—graphics quality, visual-spatial cues, interactivity—and informativeness and playfulness. However, when different experimental conditions were directly compared, the shopping interfaces with higher graphics quality were not perceived to be more informative or playful than lower graphics quality ones. Thus, hypothesis 3a and 3b were partially accepted.

4.3. The impact of playfulness and informativeness on the purchase decision

Hypothesis 4 and 5 predicts the distinctive roles of playfulness and informativeness in consumer purchase decision making. In order to identify the effect of perceived playfulness and informativeness, I ran multiple regression analysis where playfulness and informativeness were independent variables and hedonic preference and purchase intention were two separate dependent variables. The results of the multiple regression indicated that the overall regression model with informativeness, playfulness predicted hedonic preferences well ($R^2 = .23$, F (3, 213) = 31.49, $p < .001$) as well as purchase intention ($R^2 = .18$, F (3, 215) = 24.56, $p < .001$).

The results showed different patterns in the effectiveness of playfulness and informativeness on the preference for hedonic attributes and purchase intention. As predicted by H4, perceived playfulness was positively related to the valuation of hedonic benefits (t (213) = 4.67, $p < .01$), suggesting that participants considered a product's style and luxurious appeal as more significantly important consideration factors when they encountered a highly playful interface. Perceived informativeness, in contrast, did not exert a significant influence on the preference for hedonic attributes (t (213) = .58, $p = .56$). Conversely, the high level of perceived informativeness led to greater purchase intention (t (215) = 4.57, $p <.001$), whereas perceived playfulness did not exert an enhancing effect on purchase intention (t (215) = .03, $p = .97$). Finally, I tested the proposed relationship among interfaces features, informativeness, and playfulness as measured by hedonic preference and purchase intention using mediation analysis (Baron & Kenny, 1986). As predicted, both informativeness and playfulness mediated the relationship between interface features and hedonic preference and purchase intention.

To facilitate comparison and better understand the role of informativeness in purchase decision making, the survey samples were split into four grouped using median values of playfulness and informativeness to classify shopping experience in terms of playfulness (low vs. high) and informativeness (low vs. high). The primary focus of this study is to identify the role of informativeness in highly playful interfaces. Hence, the means of dependent variables of a high playfulness and low informativeness group (n = 24) were compared with a high playfulness and high informativeness group (n = 69). Informativeness played a significant role in enhancing purchase intention. Consistent with prediction, the independent t-test result shows that purchase intention (t= -3.27, p <.01) is much greater when participants experienced a highly playful and highly informative interface than when they experienced a highly playful yet not informative interface. Overall, the results provide strong support for research prediction.

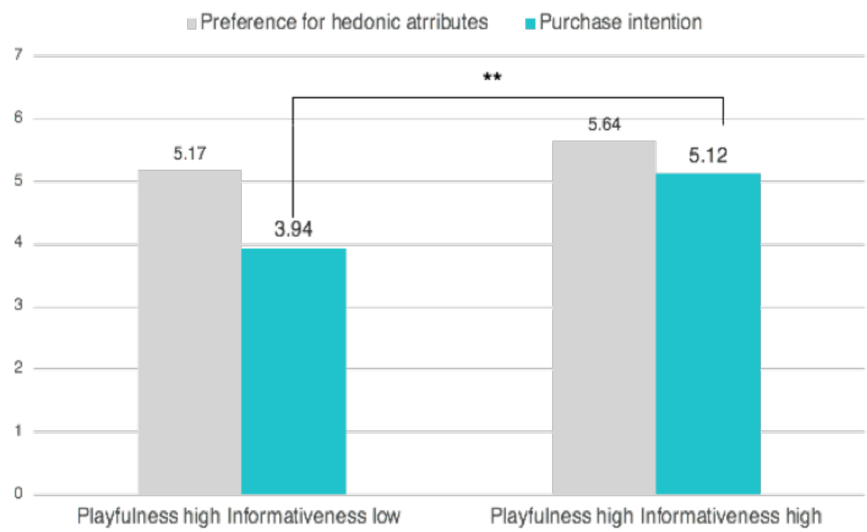


Figure 4.5. The effectiveness of informativeness on purchase intention

Table 4.4. The role of informativeness in enhancing subsequent purchase intention: M (SD)

	Playfulness high Informativeness low	Playfulness high Informativeness high	t-value
Preference for hedonic attributes	5.17 (1.23)	5.64 (1.23)	-1.55
Purchase Intention	3.94 (1.51)	5.12 (1.30)	-3.27 **

** p < .01

6. DISCUSSION

This study addresses two important questions: 1) what interface features make online shopping more informative and playful, and 2) how informativeness and playfulness influence online purchase decision-making. I particularly focused on three interface features—interactivity, visual-spatial cue, and graphics quality—in addressing these questions. As predicted, both interactivity and visual-spatial cue had a significant impact on the informativeness and playfulness dimensions of a virtual interface. Interactivity that allows shoppers to freely move and rotate the item significantly enhances the perceived level of informativeness as well as the playfulness of a shopping interface. Visual-spatial cue that visualizes the product in life-scale size with 3D stereoscopic displays is another critical factor that can make virtual shopping more informative.

One interesting result to note is the relative importance of graphics quality on 2D display and in 3D VR environments. The impact of graphic quality appears to be more pronounced when products were presented on 2D displays with images or in a 3D web environment than in the 3D VR environment. Participants exposed to immersive VR did not necessarily find a high graphic quality interface to be more informative than a lower graphics quality VR interface. This is in contrast to 3D web and image conditions where higher graphics quality is well translated into informativeness. The nature of virtual reality display and choice of product category can provide possible explanations. The virtual reality device presents users with a large number of redundant cues simultaneously (Hammond, Hamm, Grassia, & Pearson, 1987). As a result, users in VR conditions will observe multiple cues in addition to graphics quality, and therefore are more likely to assign relatively lower weights to graphic details in evaluating informativeness. Given that choice of the product was furniture, size and fit information provided by VR's stereoscopic display may have played more critical roles than graphics quality of the environment. The relative novelty of VR provides another possible explanation. All participants in our study had no prior experience with VR. Unlike 2D displays with which consumers are generally more used to high-resolution images, it is plausible that the difference in graphics quality in VR was less critical as participants have no prior expectations.

The distinctive role of playfulness and informativeness in online purchase decision making is another critical insight this research provides. Participants tend to place greater importance on visual attractiveness of a product when they experience a highly playful virtual shopping environment. Informativeness, on the other hand, is a stronger explanatory variable for purchase intention. These findings collectively suggest the important role of informativeness in online shopping. A highly playful interface may allow consumers to explore more luxurious and stylish items; however, such preference for hedonic benefits would not necessarily lead consumers to purchase the item if the virtual shopping interface is merely playful and not informative.

6.1. Contribution

This study is particularly relevant in today's rapidly developing e-commerce world. Companies have explored various forms of VR shopping, yet there is little known on how to best utilize this brand-new technology for marketing practice. This study finding is especially meaningful for online furniture retailers because large-scale luxury or designer furniture goods represent one of the toughest product segments to sell online. The findings from this study suggest that consumers are more likely to appreciate the stylish and luxurious appeal of products when products are presented in a playful 3D virtual environment than with still images and videos. However, it is important to note that playfulness alone could not lead consumers to a subsequent purchase. Retailers should keep in mind that informativeness is the bedrock of online shopping that will ultimately drive consumer's purchase intention. The study findings also suggest that more direct interaction with the product, as well as the visualization of spatial information, are all critical factors that can enhance the informativeness of online furniture shopping.

The distinctive role of playfulness and informativeness is the major contribution this research adds to the preceding literature. A dichotomy of functional and hedonic dimensions of an interface—informativeness and playfulness in this paper—has been a fertile research domain (Davis, Bagozzi, & Warshaw, 1992; Ha & Stoel, 2009; Kim & Forsythe, 2008). However, the relative impact of informativeness and playfulness on the different stages of purchase decision making has received relatively less attention. Furthermore, the majority of prior studies rarely manipulated the level of informativeness and playfulness, but many studies measured the level of informativeness and playfulness with one single stimulus. In a sense, prior studies' approach can be effective to test the role of informativeness and playfulness as a mechanism, but such an approach can be limiting for two reasons: 1) the measurement would primarily reflect individuals' perception of one single interface, 2) thus do not truly capture the interface elements of informativeness and playfulness. In this study, I view informativeness and playfulness as multi-dimensional concepts that reflect both a perceiver and an interface. This study specifically focused on three interface features—interactivity, graphics quality, and visual-spatial cues—and explored how these three components interweave with both informativeness and playfulness. To the best of my knowledge, this is the first study to incorporate these diverse interface features in analyzing the role of informativeness and playfulness in consumer online purchase process.

6.2. Limitation

An important caveat that should be mentioned is my recruitment strategy. I used different recruitment methods for VR (face-to-face survey) and other experimental conditions (online survey using Mturk). The primary purpose of using Mturk was to tap into a more diverse population that better fits the target consumer segment for furniture shopping than college students (Minton, Gruel-Atay, Kahel, & Ring, 2013). I carefully screened local participants to minimize demographic heterogeneity. A number of prior literature that compared Mturk to the traditional face to face survey methods found that the results across the samples for the same task were almost indistinguishable (Casler et al., 2013).

However, others have wondered about the reliability of Mturk samples. The recent study of Wessling, Huber, and Netzer (2017) show that a large portion of Mturk respondents claim a false identity in order to qualify for the study, suggesting that demographic similarity we saw between

Mturker and local participants may be invalid. Other studies have found that online survey participants are less invested or motivated than traditional lab participants (Gosling, Vazire, Srivastava, & John, 2004). Although there were no significant differences between attention level across survey samples, it is possible that Mturk participants simply choose the neutral answer every time to finish the survey as quickly as possible. If the answers are provided this way, the results from Mturk survey may be less accurate or truthful than the results from local VR participants.

Furthermore, the study subjects were not engaged in an actual purchase but “simulating” shopping. Subjects tend to pay less attention to the shopping environment when they are merely simulating purchase (Burke, Harlam, Kahn, & Lodish, 1992b). The study results support the importance of informativeness in general, but it is highly possible that informativeness would play an even more crucial role in actual shopping condition.

6.3. Conclusion

This research highlights how virtual reality has the potential to make current online shopping more informative and playful. High level of interactivity and visualization of spatial information are two factors that can significantly enhance the informativeness and playfulness of virtual shopping. This study also examined the distinct roles of informativeness and playfulness. The study results indicate that a more playful interface can substantially increase the chance of exploring hedonic items, whereas informativeness is a more critical factor for purchase intention. Virtual reality has the potential to revolutionize retail, yet companies are still experimenting with how to best implement VR into their business strategy. While there are many remaining questions yet to be answered, the insights from this study can provide constructive guidelines for scholars and practitioners in the field of marketing.

STUDY 3 Designing 3D User Interaction

A Comparative Analysis of 3D Interaction: How to Move Large Object in AR

1. INTRODUCTION

The research into human-computer interaction has long explored the question: what would be the most natural way to interact with the virtual object? Physical and tangible devices like a keyboard, mouse, and joystick have been dominant input devices for decades (Preece et al., 1994). The advent of touchscreen made people quickly embrace a more familiar yet innovative form of input device—the bare hand. The use of hand input has been received much attention in the HCI community with the growing popularity of head-mounted virtual reality (VR) and augmented reality (AR) device. As opposed to hand-held controllers, integration of hand tracking eliminates the need of carrying additional devices, making hand inputs more appealing for wearable augmented reality headsets.

In this study, I examine hand-based 3D user interaction design for wearable AR devices. The major goal of this study is to understand how to design a 3D user interaction for a head-worn AR device that is easy and intuitive to use. I particularly focus on the interaction that involves moving large objects. Manipulating large virtual objects like furniture with hands poses several challenges. When a user tries to grab a nearby object, the large size object can easily block the view of the users, making it challenging to maneuver the object around. If an object is farther away from the users, it is easier to see the entire shape of the object, but using hand inputs in such case imposes a significant constraint: users can not directly manipulate the object when it is beyond their arm's reach.

In order to address the aforementioned concerns, previous research proposed various 3D user interaction techniques. For instance, Microsoft Hololens utilizes a multimodal interaction that combines gaze input and a pinch gesture to manipulate the remote objects. The Worlds in Miniature (WIM) interaction, proposed by Stoakley (Stoakley, Conway, & Pausch, 1995), allows users to easily manipulate the large size object by providing multiple points of view at different scales; the miniature size of objects alongside with real-life scale of objects. HCI literature abounds with the discussion of innovative techniques to interact with a virtual object; yet, the relative merits of these interaction techniques for wearable AR device has been little explored (Kytö, Ens, Piumsomboon, Lee, & Billinghurst, 2018). Hololens' multimodal interaction and the Worlds-in-Miniature interaction may be more convenient ways to interact with large virtual objects, but they may seem less natural and intuitive than a conventional touch and grab interaction.

This study presents and compares three 3D interaction techniques; 1) multimodal interaction with gaze and pinch gesture, 2) worlds-in-miniature, and 3) touch and grab interaction. Each of these interaction modalities has its own advantages and disadvantages. The goal of examining these three interaction techniques is to systematically evaluate widely-known interaction techniques, thereby providing insights for designers to improve current hand-based interaction designs. I created three AR environments that utilize each interaction technique and conducted a user study with people who have no prior experience with head-worn AR devices.

Another goal of this study is to identify other possible interactions that may render easier and more effective than three interaction techniques. Hands are capable of a variety of actions by nature—point, reach, pinch, grab and push—yet the question of how to map various hand inputs to virtual object manipulation tasks still remains an open question. In this study, I observed the gestures participants used and analyzed their hand movements. Analysis of participants' hand gesture can provide insights into designing more natural 3D interactions. The study aims to answer the following research questions.

1) *Learnability:* which interaction mechanism requires a greater time investment to figure out?

2) *Performance:* which interaction mechanism offers the user an increased efficiency and effectiveness to complete the task?

3) *Naturalism and usability:* which interaction mechanism is more intuitive and easier to use? Are there other possible interaction designs that users might find more natural and intuitive?

I structure the rest of this study as follows: I begin with discussions of the definition of the term “naturalism,” and examine prior studies that compare different interaction techniques. I then provide a description of the three interaction designs used for this study. From the user study result and observation of participant’s gestures, I present design strategies that can aid AR designers in developing more natural and intuitive 3D user interactions.

2. RELATED WORKS

In this section, I discuss the meaning of naturalism in HCI research and explore the relative merits of different interaction techniques by examining prior research that compared existing 3D user interaction techniques. It is beyond the scope of this paper to fully review all existing 3D user interaction techniques, nor this paper attempts to comprehensively cover the overarching theory of naturalism and usability of 3D user interaction. In this exploratory work, I limit my investigation to three interaction techniques. A comparison study on three popular interaction designs can be the first step toward a comprehensive understanding of hand-based 3D user interaction design.

2.1. Naturalism in 3D User Interaction

The meaning of the term naturalism varies widely depending on the field of study. In the field of human-computer interaction, the term describes user interaction design that mimics the counterparts of the real-world interaction. Bowman et al (Bowman, Mcmahan, Ragan, 2012) define naturalism as the degree to which the action used for a task corresponds to the action used for that task in the real world. As an instance, for a selection task, grabbing an object with a hand is more natural than using eye gaze inputs to accomplish the same task (Bowman, McMahan, & Ragan, 2012). For a manipulation task, dragging an object around to change its position is more natural than using a joystick or pressing a sequence of buttons (Rautaray & Agrawal, 2012).

A natural 3D user interaction is well known for its benefit of minimizing a learning curve (Bacim et al., 2013; Bowman et al., 2012b). The familiarity serves as important cues when people make inferential judgments, allowing people to readily predict how an object can be interacted with (Villaroman, Rowe, & Swan, 2011). Previous virtual reality user interface studies suggest that use of familiar interaction mechanism can drastically help users to understand how to interact with the virtual objects in a 3D space (Bacim et al., 2013). Enhanced level of enjoyment is another benefit of naturalistic interactions. Naturalistic interactions are known to facilitate the sense of being present in a virtual environment, thereby making virtual interaction more engaging and enjoyable to interact with (Skalski, Tamborini, Shelton, Buncher, & Lindmark, 2011). For example, Skalski and his colleague (2011) found that when participants used a more natural interaction, use of a steering wheel for a driving task, they felt a greater level of enjoyment compared to the cases when participants used a keyboard and a mouse.

Despite its benefit of being intuitive and enjoyable, natural interaction does not necessarily result in better performance (Bowman et al., 2012; Bowman, Gabbard, & Hix, 2002). Some interactions are intentionally less natural because such a less naturalistic interaction might be more effective at a certain task (Cockburn, Quinn, Gutwin, Ramos, & Looser, 2011). To select an object from a distance, for instance, the most natural way would be to force users to walk over and grab the object, but this involves more physical movement and can be more time consuming than simply staring at the target object to accomplish the same task. Natural mapping has limitations as well as benefits, hence, it is worth examining the perceived level of naturalism and its relative merits in the context of AR 3D user interaction.

2.2. Existing Techniques for Selection and Manipulation

In the real world, selecting and manipulating an object generally involves directly touching an object and physically moving it with arm movement. It is not surprising the most common technique in a 3D virtual environment is based on ***direct touch and grab*** actions with a real hand movement (Bowman et al, 2012). For developing VR environments, touch and grab interactions are a standard way to implement object manipulation (Bowman, 1999). While being considered as the most natural, the primary issue with a direct touch-grab interaction is that users can only interact with objects within their arms' reach.

The ray-casting technique, which uses a virtual ray extending from an input device (Liang & Green, 1994; Matulic & Vogel, 2018), allows a user to select the remote objects. Pointing an object with an index-finger is considered as a natural way to use a ray-casting technique; however, holding a finger in the air for a long time can cause fatigue and suffer from natural hand tremor (Kytö et al., 2018). In order to address this issue, a number of head-worn VR/AR devices combines ray-casting techniques with head or gaze-directed pointing. Microsoft Hololens' multimodal interaction is one of the most well-known examples that combine ***gaze and gesture***. Users can select the target the object with their head movement, which works as a proxy for eye gaze, and selects the object with a pinch gesture.

The ***Worlds-in-Miniature*** (WIM) technique (Stoakley, Conway, & Pausch, 1995) provides users miniature copies of the actual objects so that users can directly interact with the object no matter how far the actual objects are. While still allowing users to have a natural and direct interaction, this WIM technique requires less physical movements because users don't have to walk around to position a virtual object (Stoakley et al., 1995; Trueba, Andujar, & Argelaguet, 2011).

Touch and Grab
(Virtual Escape Game, Steam VR)

Gaze and Gesture
Microsoft Hololens (Press image)

World in Miniature
(Stoakley, Conway, & Pausch, 1995)

Figure 5.1. Three 3D user interaction techniques for manipulating a virtual object

Although this technique is not as widely used as the other two techniques, miniature metaphor particularly works well for interacting with large objects, making WIM a popular technique for 3D interior design applications (e.g. TrueScale at Steam VR).

2.3. Comparative Studies on 3D User Interaction Techniques

In evaluating 3D user interactions, accuracy and efficiency have been a fertile research topic in the field of virtual reality and 3D user interface (3D UI). In order to find a more effective way to interact with a remote object in a VR environment, Bowman and Hodges (1995) compared the six different 3D manipulation techniques. In their comparative study, an extended-virtual arm metaphor was considered as more natural than a conventional ray-casting—a virtual ray emanating from a controller. However, their findings suggested that a conventional ray-casting offered more precise control in manipulating virtual objects. Kyto et al (2019) examined selection techniques for head-worn AR device. They found that head-movement was generally faster and efficient than using a hand-gesture or a hand-held device. In a similar vein, several research reported head-directed pointing being faster than hand-directed pointing on a large stereoscopic projected display (Sibert & Jacob, 2000).

Aside from accuracy and efficiency, perceived usability is another critical dimension in evaluating 3D user interaction techniques. Bernardos, Gómez, and Casar (2016) compared the head-directed selection to the hand-based pointing on a projection screen. While there was no significant difference in terms of accuracy, users found hand-based pointing far more intuitive and usable than head-directed selection. McMahan et al. (2007) compared three interaction techniques on the projected wall: hand-centered object manipulation called HOMER, ray-casting techniques, and a conventional input using a keyboard and mouse. Study participants found hand-based object manipulation far more natural than using a keyboard and mouse or a conventional ray-casting technique.

In summary, much of prior research showed that more naturalistic interaction—an interaction that uses a hand rather than head movement, or a virtual arm metaphor than ray-casting—provides better usability. However, when it comes to accuracy and efficiency, several works showed that perceived naturalism is not a necessary component in resulting in better performance. While these prior study findings provide insight into evaluating existing 3D user interactions, the differences across experiment settings preclude any generalizable conclusion. Prior works on 3D user interaction have predominantly focused on interaction with a large projected wall and head-mounted VR displays, and relatively little is known for wearable AR displays context. Furthermore, most of the previous comparative studies tend to focus on a specific interaction task, for example comparing head tracking to eye tracking for a selection task (Kyto et al, 2019), two different ray-casting mechanisms for a pointing task (Buchmann, Violich, Billinghurst, & Cockburn, 2004; Cockburn et al., 2011), two different finger-based projection methods for a manipulation task (Matulic & Vogel, 2018). In this study, I aim to provide a more comprehensive understanding of 3D user interaction by examining three interaction techniques in accomplishing three tasks—menu selection, object selection, and object manipulation. Contribution of this study lies in providing a broader comparison of these widely-known 3D UI techniques thereby offering insights for designers to improve the current 3D user interaction designs.

3. DESIGN IMPLEMENTATION

This section provides a description of three interaction designs used for this study: 1) gaze and pinch, 2) touch and grab, and 3) world-in-miniature. In order to implement three interaction techniques, I created three AR interfaces using ZED mini with Oculus Rift. For this exploratory study, I exclusively focused on three different tasks: menu selection, object selection, and object manipulation. Compared to other interaction tasks such as navigation and system control, another popular research topic in the field of VR, these three tasks are more relevant in the context of interacting with furniture.

3.1. Device Setup

I used an Oculus Rift with Leap Motion and ZED Mini camera. ZED Mini is an attachable depth-camera which features dual 2K image sensors and provides augmented-reality experience for head-worn VR devices. The purpose of using ZED mini, instead of more popular head-worn AR devices such as Microsoft Hololens, is to achieve a wider field of view. The most notable drawback of the original Hololens is its small field of view, which is largely limiting when users are interacting with a large size object. ZED mini offers 110-degree fields of view, almost three times wider than what Microsoft Hololens provides. Both ZED mini and Leap motion were mounted on the Oculus Rift headset as seen in figure 5.2. All these devices were run on an Alienware PC (Intel Core i7-770K with NVIDIA GeForce GTX 1070). The tracking was set up with Oculus two sensors and the size of the tracking area was approximately 3 meters by 2.5 meters.

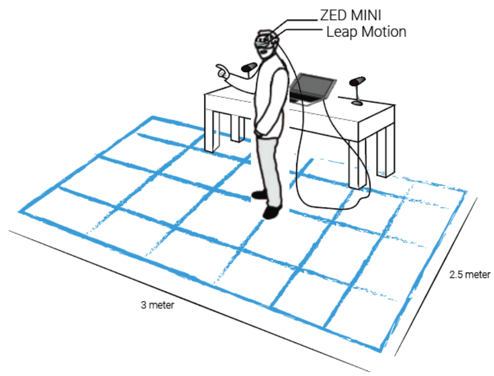


Figure 5.2. Device setup (left), Room setup with Oculus sensors (right)

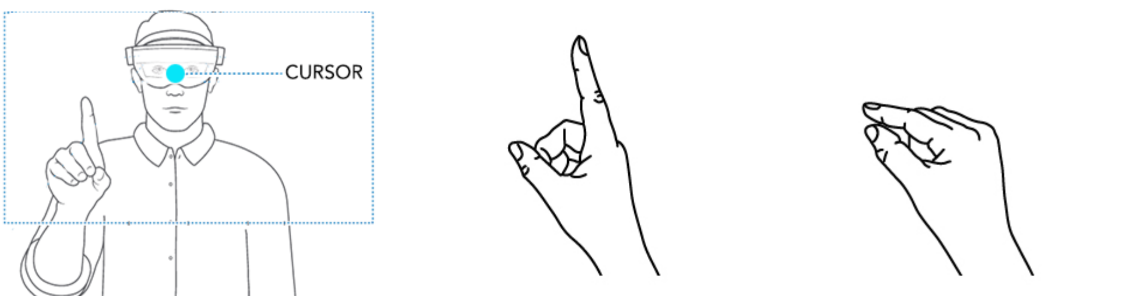
3.2. Gaze and Pinch Interaction

The *gaze and pinch* interaction uses head-movement as a proxy to eye gaze and pinch or air-tab gestures to accomplish the selection task. The purpose of implementing this gaze and pinch interaction is to simulate Microsoft Hololens' multimodal interaction. The standard way to select the object with a Hololens is to use a gesture called "air-tab," which refers to the action of pressing the extended index finger toward the thumb as shown in figure 5.4. Given the similarity between an air-tab and a pinch gesture, I use a more general term "pinch" instead of using the term "air-tab," in this paper.

The three tasks are implemented in the following way: menu selection was evoked when the gaze cursor was targeted at the menu button. As the user releases the index finger, the virtual object appears in front of the user. Object selection was evoked when the object was targeted with the gaze cursor. For the manipulation task, a user could change the position of the virtual object by holding a pinch gesture. The virtual object moved along with the hand's movement. Following the Hololens' approach, visual cues such as highlighting and a movement box are provided as seen in figure 5.3. This interaction allows users to select and manipulate the remote object and doesn't require the user to physically walk around the space to position the object.

Menu Selection: Gaze and Pinch Object Selection: Gaze Object Manipulation: Pinch

Figure 5.3. Gaze and Pinch Interaction: target the menu with gaze and accomplish the selection task by releasing an index finger (left). Select the virtual object with a gaze (middle) Hold a pinch gesture to move the object around (right)



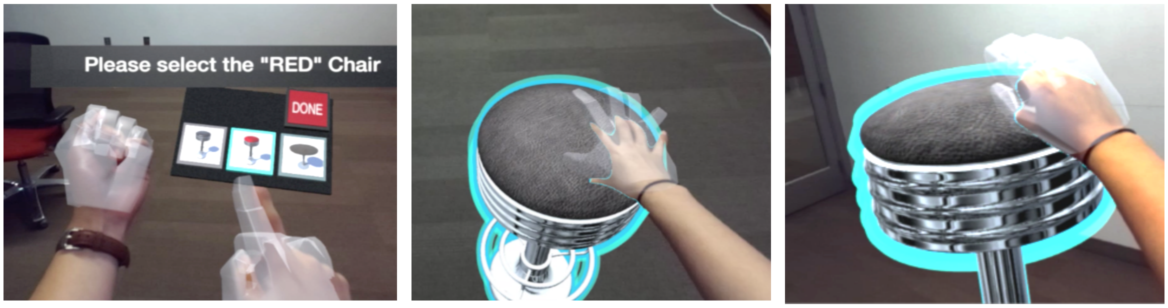
Gaze cursor to select the target Finger in the ready position Press to accomplish the selection

Figure 5.4 Illustration of two core inputs of Microsoft Hololens: Gaze (left) and air-tab hand gesture[1]

3.3. Direct Touch and Grab Interaction

The *grab and touch* interaction have been a standard way to interact with a virtual object in a VR environment, especially for the head-mounted VR devices such as Oculus Rift and HTC Vive. The conventional way to implement a touch-grab interaction in VR is to use a controller: for the selection task, users should touch the virtual object with a controller. In order to grab the selected item, users should press the grip button. Since the focus of this study is on hand-based

[1] Image reference: "Gestures", *Microsoft Mixed Reality*, Feb 2019, https://docs.microsoft.com/en-us/windows/mixed-reality/gestures, Accessed July 15, 2019



Menu Selection: Direct touch

Object Selection: Direct touch

Object Manipulation: Grip

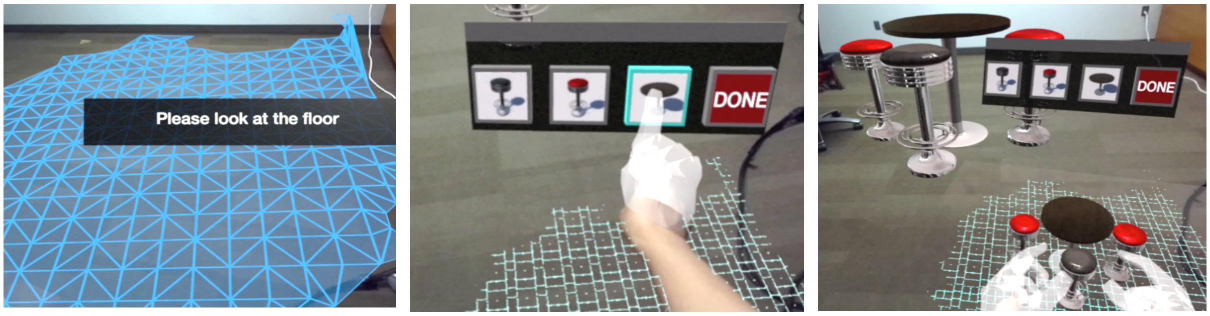
Figure 5.5. Direct Touch and Grab: select the menu by touching the menu icon. The menu is attached to the left hand of the user (left). Select the object by directly touching it with a hand (middle). Move objects by gripping it (right)

interaction, I used grip gesture—a gesture of making a fist—in order to activate grabbing action. Object selection and manipulation are implemented as follows: to select the object, the users should walk to the virtual object and touches it with their hand, then use a gripping gesture to grab and move the object.

In implementing the menu selection task, I used the attached menu metaphor proposed by Leap Motion (Leap Motion, 2018). As seen in figure 5.5, the attached menu can be activated as the users flip their left hand. I used this attached menu metaphor for two reasons: first, this menu selection mechanism corresponds well to direct touch and grab interaction because the menu should be directly touched with users' finger to be invoked. Second, this attached menu minimizes unnecessary physical movement involving menu selection, such as walking to the menu, thus enables better comparisons with other conditions.

3.4. Worlds in Miniature Interaction

The last interaction technique uses a world-in-miniature metaphor. Unlike the previous two interactions where users can directly select and move the actual-scale object, this interaction provides the users with the hand-held miniature representation of the actual-scale objects (Stoakley



Plane Detection: Scan the space to create the miniature space

Menu Selection: Direct touch

Object Selection & Manipulation: Direct Touch and Grip

Figure 5.6. Worlds in Miniature: Scan the area to create the miniature space (left). Select the menu by touching the menu icon (middle). Select and move the object by manipulating miniature size object (right).

et al., 1995). By moving the miniature size object, users can move the corresponding actual-size object as seen in Figure 5.6. Other than three interaction tasks—menu selection, object selection, and object manipulation—this worlds-in-miniature involves an additional task, generation of the miniature space. In order to interact with the miniature items, users should create a miniature room to place the miniature items. The first task for the users was to scan the surrounding environment. Using ZED mini's depth-camera, the floor of the room was detected, then the miniature size of the detected floor area was created at a scale of 0.2 as seen in Figure XY (middle image). After the generation of the miniature floor, the menu appeared in front of the user. Users were able to select and move the miniature object, 0.2 scales of the actual object, by directly manipulating it with touch and grip gesture.

4. USER STUDY

I conducted a user study to compare three interaction designs. This user study aims to address two objectives: 1) to evaluate the usability and effectiveness of three interactions, and 2) to identify hand gestures that users might find more intuitive and natural than three interaction techniques. In order to address these two goals, both quantitative and qualitative data was measured throughout the user study. This section provides a detailed description of the experiment design, procedure and study measurement.

4.1. Task

With each interaction condition, participants were asked to complete three tasks: *1)* select the menu to choose a virtual object; *2)* move the object to the designated area, and *3)* arrange multiple furniture items. Figure 5.7 shows an overview of the three tasks and the experiment procedure. A virtual object always appeared at the same distance from the user to ensure consistency across three conditions.

The primary purpose of *task 1* and *task 2* is to examine the learnability of each interaction, thus a minimum level of instruction was provided to participants. For example, for gaze-pinch interaction, participants were told to "use a hand-gesture to select/move the object," and no further information about what gesture users should use was provided. For touch-grab interaction, participants were simply told to "use a hand-action to activate the menu," and no further information was provided about how to select and move the virtual object. If the users couldn't figure out how to select/move the object within two minutes, the task was marked as *failed* then users were asked to move to the next task.

The goal of *task 3* is to measure the effectiveness and efficiency of each interaction. Detailed instructions of how to interact with the virtual objects were provided before the task 3. After a brief trial, participants were asked to select two red stools, two black stools, and one table, then arrange the four chairs around the table so that each chair is perpendicular to each other. The total time it took to complete the task was measured as an indicator of efficiency and the angle between each chair was measured as an indicator of accuracy and effectiveness. In order to better compare the efficiency of each interaction, the virtual stool and table always appeared at the same

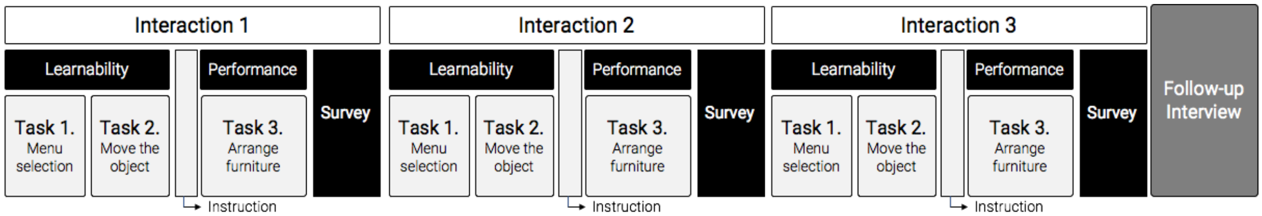


Figure 5.7. Overview of the task and experiment procedure: the box with the grey background indicates the task. The box with the black background indicates the measurements.

distance from the user across the condition. After the completion of all three tasks, participants evaluated the interaction design. These three tasks are repeated for 3 interactions.

4.2. Participants

When comparing different interfaces with quantitative measures, Nielson claims that researchers should recruit at least 20 users to get statistically significant numbers (Nielson, 1994). For the within-subject user testing, this number can be smaller (Nielson, 1994). Based on this claim on sample numbers, 21 participants (12 females) were recruited through mailing lists and flyers in the campus. Participants' age ranged from 18 to 44 with a mean of 24.2 (SD = 7.8) and the majority of them were university students. Since the goal of this study is to examine the learnability for handheld AR interactions, I specifically sought participants who have no prior experience with head-worn AR devices. Although none of the participants experienced wearable AR devices, 9 participants had prior VR experience with Oculus Rift or HTC Vive. 4 participants identified themselves as a heavy video gamer who play video games almost every day, but about 60% of participants indicated that they don't play a video game or play it less than once a month. On average, participants spend a significant amount of time working on a computer on a daily basis (5-8 hours a day: 47%, more than 8 hours: 28%).

4.3. Experiment Procedure

The primary goal of the study was to compare three different interactions, thus this study employed a within-subject study design. Participants experienced all three interaction in a randomized order and were asked to pick one interaction design they preferred the most and explained why. In order to minimize the learning effect, each session was fully counter-balanced. For each interaction, participants completed 3 tasks then they evaluated the interaction by answering questionnaires. Participants completed 9 sessions in total (3 tasks X 3 interactions) and all of these sessions were recorded using a screen recorder. Figure 5.7 illustrates the overall procedure of the experiment. Finally, they were asked to complete the final survey that includes questions on demographic information and their average computer usages. After the completion of the survey, participants were invited for a follow-up interview. The entire process approximately took 45 minutes and participants received $10 compensation. All protocols were approved by the University's ethics committee and conformed to the guidelines provided by the University's institutional review board.

4.4. Measures

4.4.1. Evaluation of three interaction designs

Learnability: Learnability is the ease of with which a software application can be picked up and understood by users (Preece et al., 1994). The better learnability the system is, the less training and time it will take for a person to use it. The learnability of each interaction was examined by measuring the time it took to complete the task 1 and task 2. When participants couldn't figure out the interaction for longer than two minutes, the learnability of the task was marked as "failed." The pilot study indicated that people feel a great level of frustration when they failed to interact with the virtual objects after they spend longer than one and a half minute.

Performance: The performance of the users was evaluated with two items—efficiency and accuracy. The efficiency of interaction design was examined by measuring the time it took to complete the task 3. When users finished arranging furniture, they were asked to press the button, then the total time it took until the button click was recorded. The accuracy of interaction design was examined using position data of five furniture items: four stools, and one table. Participants were asked to arrange four stools so that they are perpendicular to each other. The average deviation from 90-degree was calculated to examine accuracy.

Usability: The perceived usability of each interaction design was evaluated using the System Usability Scale (SUS; Brooke, 1986). The system usability scale includes 10 items with five responses that range from strongly agree to strongly disagree. The example questionnaire includes: “I found the system was easy to use,” “I would imagine that most people would learn to use this system very quickly,” and “I felt very confident using the system.” In interpreting SUS, the participant’s score is converted into 100, by multiplying adjusted item score by 2.5. Previous research indicated that a SUS score above 68 would be considered above average Brooke, 1986. In order to examine perceived task loads, the NASA Task Load Index (NASA-TLX) questionnaire was also included in the survey. The NASA-TLX is a widely used multidimensional assessment tool that rates the perceived workload (Hart, 2012). Users are asked to indicate mental demand, physical demand, temporal demand, performance, effort and frustration level using bar scales. The score was converted to 100 (Hart, 2012; Hart & Staveland, 1988).

Naturalism and Enjoyment: To measure the perceived level of naturalism, or often termed as interaction fidelity in VR research, I developed five-point Likert scale questionnaires based on prior research on interaction fidelity (Nabiyouni, Saktheeswaran, Bowman, & Karanth, 2015). The questionnaire includes three items: “interaction with a virtual object was similar to how I would interact with an object in a real-world,” “interaction with a virtual object felt familiar,” “interaction with a virtual object seems intuitive and natural." The questionnaire for the enjoyment was adopted from previous literature on extended Technology Acceptance Model (TAM, Davis, 1989). The questionnaire includes two items: "It was enjoyable to use this system," "It was fun to use this system." Cronbach's alpha for both variables was above 0.7 ($\alpha_{naturalism} = 0.78$; $\alpha_{enjoyment} = 0.81$).

Control variables: Responsiveness of the system was included as a control variable. The questionnaire asked participants whether they experienced system lag when they experience each interaction design. Participants' demographic information, as well as their previous experience with VR, video game, and average daily computer use, were also measured. The entire list of the survey questionnaire is seen in Appendix.

4.4.2. Gesture analysis and follow-up interview

Gestures: Studying gesture can help 3D UI designers to find suitable interface features that correspond well to users' expectation (Rautaray & Agrawal, 2012). In this study, I particularly focused on the users' hand movement. Following Kendon (1972)'s gesture analysis method, the session was video-recorded and changes of gestures were encoded with a description of the movement change. The purpose of this analysis is to identify gestures participants use when they first encounter the virtual object, thus the video recordings of task 1 and task 2 sessions were mainly used for the analysis. The hand movement is described with three main elements: a number of hands used, specific gesture used, and a target object. The examples of description include: pressing the button with an index finger, lifting the table using both hands, pushing the chair with one hand, gripping the top of the chair, and more. The gesture analysis and follow-up interview were focused on understanding how users act and why.

<u>*User experience:*</u> In order to better understand participants' experience with three interaction designs, a follow-up interview was conducted. The interview questions mainly include five items: 1) which interaction did you prefer the most? 2) why do you prefer interaction X over others? 3) what do you like or dislike about other interactions? 4) What's the hardest part about the interaction you experienced? 5) How would you like to provide a solution to make an improvement? In addition to these five questions, I also asked questions based on my observation, for instance, what specific gesture participants used to interact with the virtual objects and why.

5. RESULTS

This section presents the results of the data analysis. Quantitative data including the total time it took to finish the tasks, the accuracy of manipulation, as well as the subjective ratings of perceived usability, naturalism, and enjoyment are analyzed using a repeated-measure of analysis of variance (ANOVA). Behavioral measures such as frequency of hand gesture used per participant and results from the follow-up interview are also reported in this section.

5.1. Evaluation of Three Interaction Designs

5.1.1. Learnability

In order to examine the learnability of each interaction design, the time it took for participants to complete the first task (menu selection) and the second task (object selection and manipulation) was compared. ANOVA analysis shows a significant main effect for both tasks (menu selection: F (2, 51) = 11.13, p < .001, η_p^2= .303; object selection and manipulation: F (2, 50) = 9.67, p <.001, η_p^2= .283). Turkey's HSD post hoc test was conducted for pair-wise comparisons. The result of the analysis is shown in Figure 5.8.

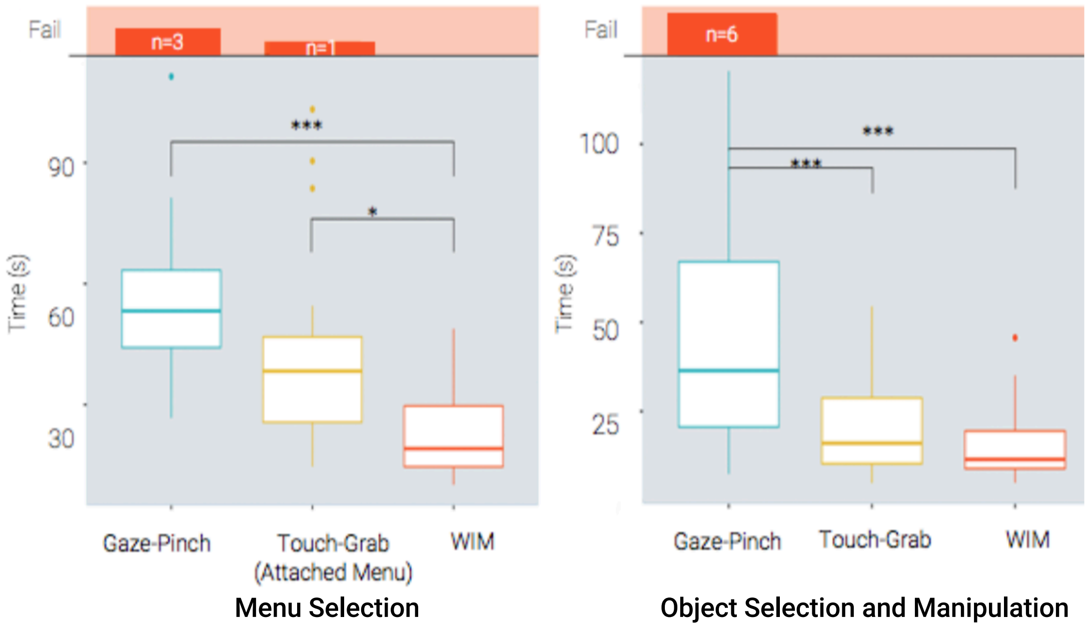


Figure 5.8. The learnability of each interaction was measured with the total time it took to complete the task. * indicates p <.05, ** indicates p < .01 *** indicates p <.001

For the menu selection task, gaze-pinch interaction took the longest amount of time to complete the menu selection ($M_{\text{gaze-pinch}}$= 54.88, $SD_{\text{gaze-pinch}}$= 20.47; $M_{\text{touch-grab}}$= 42.83, $SD_{\text{touch-grab}}$= 25.57; M_{WIM}= 23.69, SD_{WIM}= 12.27). Among 21 participants, 3 participants failed to complete the menu selection task with gaze-pinch interaction. For the majority of the participants, except one participant who indicated that he figured out pinch gesture in the follow-up interview, the menu was accidentally selected as participants tried to grab the menu button—which naturally involves the pinch gesture. It took significantly less time to select the menu with worlds-in-miniature interaction than gaze-pinch interaction ($p < .001$) and touch-grab interaction with which users had to flip their hand to activate the menu ($p < .05$).

In regard to the object selection and manipulation task, gaze-pinch interaction took a significantly longer amount of time to complete the task ($M_{\text{gaze-pinch}}$= 49.20, $SD_{\text{gaze-pinch}}$= 38.33; $M_{\text{touch-grab}}$= 21.57, $SD_{\text{touch-grab}}$= 14.50; M_{WIM}= 15.92, SD_{WIM}= 11.04). 6 participants failed to accomplish the task within 2 minutes with the gaze-pinch interaction. There was no significant difference between grab-touch interaction and worlds-in-miniature interaction in regard to the total time taken to complete the object selection and manipulation task (p =.765)

5.1.2. Performance: Accuracy and Efficiency

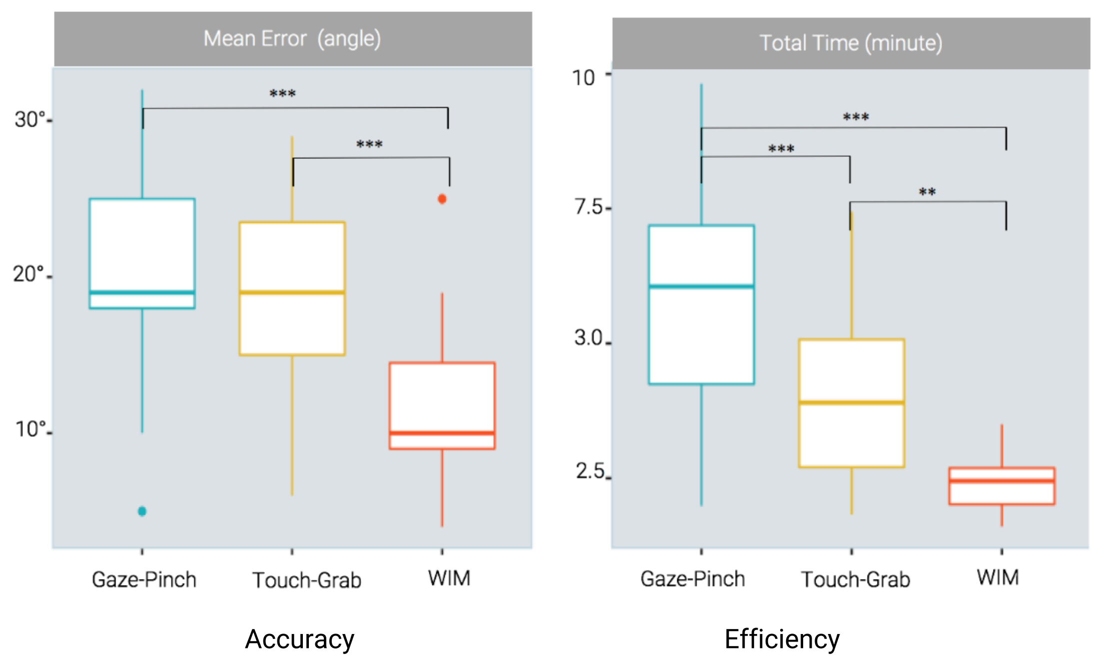


Figure 5.9. The accuracy of each interaction was measured with the mean error in angle (angular differences from a 90 °right angle). The efficiency of each interaction was measured with the total time it took to complete the object selection and manipulation task.
* indicates p <.05, ** indicates p < .01 *** indicates p <.001

The object manipulation task involved arranging four stools around the table so that each stool is perpendicular to each other. Accuracy of manipulation was calculated with the angular differences from a right degree. Cosine value of the angle between two vectors was calculated then was converted into angle degree. Mean of absolute angle was used to represent the accuracy of each interaction design. ANOVA analysis shows a significant main effect on accuracy for different interaction designs (F (2, 54) = 8.58, p < .001, η_p^2= .241). Turkey's HSD post hoc test was conducted for pair-wise comparisons. The result of the analysis is shown in Figure 5.9. The pair-wise comparison results show that mean manipulation error was significantly lower for worlds-in-miniature interaction design than other two interaction techniques ($M_{\text{gaze-pinch}}$= 20.36, $SD_{\text{gaze-pinch}}$= 7.31; $M_{\text{touch-grab}}$= 18.42, $SD_{\text{touch-grab}}$= 6.85; M_{WIM}= 12.01, SD_{WIM}= 5.16). There was no significant difference gaze-pinch and touch-grab interaction in regard to the accuracy. The efficiency of each interaction was measured with the total time it took to finish the object selection and manipulation task (task3). ANOVA analysis shows a significant main effect on efficiency for different interaction designs (F (2, 54) = 29.23, p < .001, η_p^2= .519). The Turkey's HSD pair-wise comparison test shows that worlds-in-miniature was significantly faster to complete the task than the other two interaction techniques ($M_{\text{gaze-pinch}}$= 5.90, $SD_{\text{gaze-pinch}}$= 2.08; $M_{\text{touch-grab}}$= 3.98, $SD_{\text{touch-grab}}$= 1.56; M_{WIM}= 2.44, SD_{WIM}= 0.51).

5.1.3. Usability, Naturalism, and Enjoyment

Usability of the interface was measured with two indexes: the NASA-Task Load Index (NASA-TLX) and System Usability Scale (SUS). The ANOVA results for NASA-TLX is shown in figure 5.10. There was a significant main effect for mental load (F (2, 53) = 10.04, p < .001, η_p^2= .278), physical load (F (2, 54) = 4.84, p < .05, η_p^2= .152), performance (F (2, 54) = 6.97, p < .01, η_p^2= .204), effort (F (2, 54) = 38.29, p < .001, η_p^2= .586), and frustration (F (2, 54) = 23.09, p < .001; η_p^2= .461). No significant main effect was found for the temporal load.

The results from pair-wise comparisons between three interaction designs indicated that the gaze-pinch interaction, as well as the touch-grab interaction, are significantly more demanding than worlds-in-miniature interaction both mentally (p <.001) and physically (p <.001). The touch-grab interaction required a significantly higher level of effort than touch-grab interaction (p <.05) and the worlds-in-miniature interaction (p <.001) and evoked a significantly higher level frustration than touch-grab interaction (p <.001) and worlds-in-miniature interaction (p <.001).

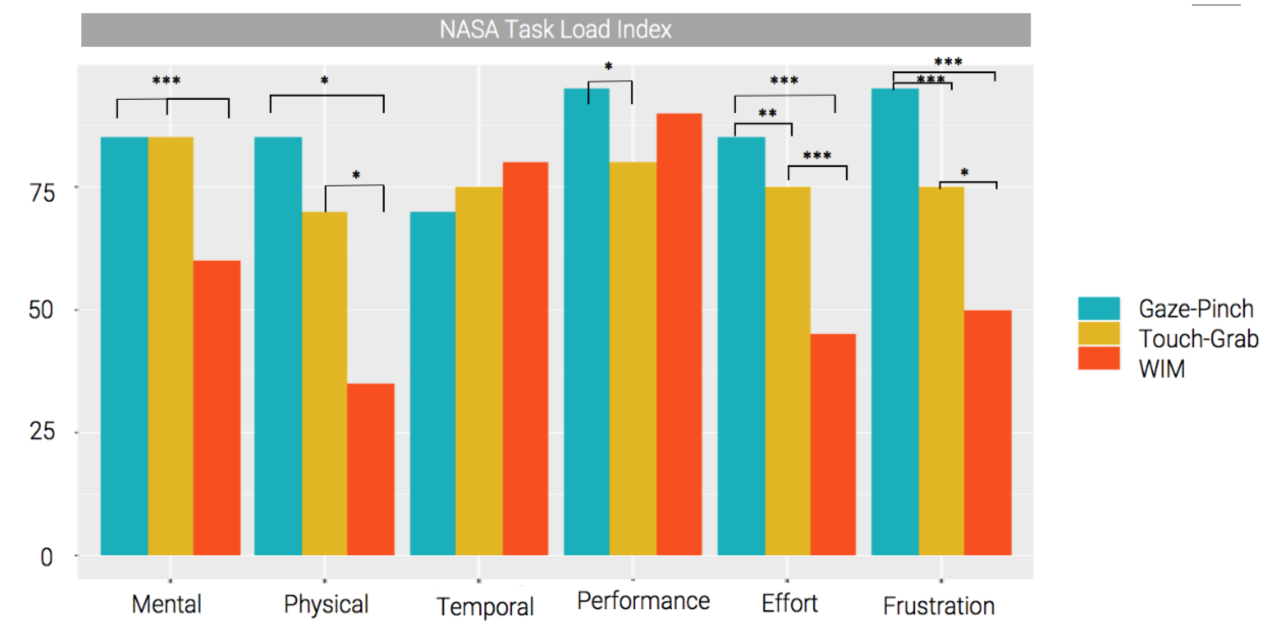


Figure 5.10. NASA Task Load Index with three interaction: NASA TLX index assesses the perceived workload required to complete the task. * indicates p <.05, ** indicates p < .01 *** indicates p <.001

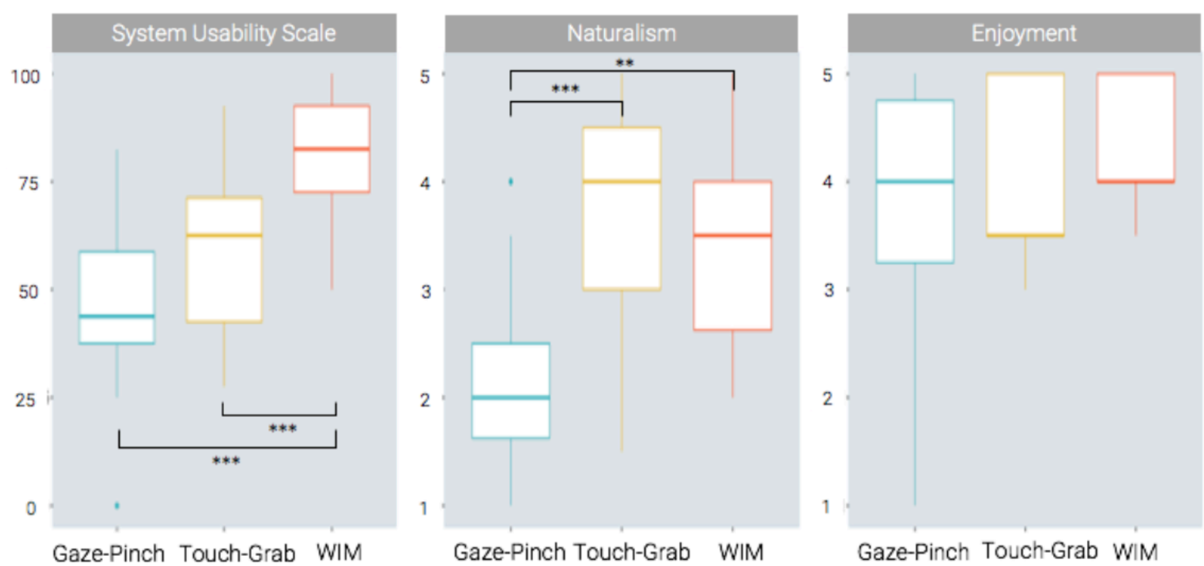


Figure 5.11. The results on users' rating of system usability scale, naturalism, and enjoyment of each interaction design. * indicates p <.05, ** indicates p < .01 *** indicates p <.001

The ANOVA results on system usability scale (SUS), perceived naturalism, and enjoyment are shown in figure 5.11. The significant main effects were reported for system usability (F (2, 54)

= 20.13, $p < .001$; $\eta_p^2 = .431$) and perceived naturalism ($F(2, 51) = 13.35$, $p < .001$; $\eta_p^2 = .343$), yet no significant effect was found for enjoyment ($F(2, 54) = 2.41$, $p = .09$; $\eta_p^2 = .081$). The pairwise Tukey HSD test shows that the worlds-in-miniature interaction provides significantly better usuability than other two interactions ($M_{\text{gaze-pinch}} = 45.97$, $SD_{\text{gaze-pinch}} = 18.39$; $M_{\text{touch-grab}} = 57.61$, $SD_{\text{touch-grab}} = 19.22$; $M_{\text{WIM}} = 81.31$, $SD_{\text{WIM}} = 13.92$). In terms of perceived level of naturalism, both touch-grab and worlds-in-miniature interaction were rated to be significantly more natural than gaze-pinch interaction ($M_{\text{gaze-pinch}} = 2.25$, $SD_{\text{gaze-pinch}} = 0.92$; $M_{\text{touch-grab}} = 3.77$, $SD_{\text{touch-grab}} = 0.97$; $M_{\text{WIM}} = 3.41$, $SD_{\text{WIM}} = 0.87$). However, there was no significant differences between touch-grab and worlds-in-miniature interaction ($p = 0.38$), suggesting that participants found worlds-in-miniature just as natural and intuitive as touch-grab interaction.

5.2. Gesture Analysis and Follow-up Interview

5.2.1 Gesture analysis

I analyzed the video recording of participants' hand movement by systematically categorizing and labeling gesture they used. Due to the recording error, the videos of 17 participants were used for the analysis. Table 5.1 shows a summary of the findings from gesture analysis. When participants first encountered the gaze-pinch interface, in which the menu was displayed far away from the user, the first action all participants tried was to press the menu button with an index finger. When pressing gesture failed to evoke the menu selection, 14 participants walked or lean toward the menu and tried to press the button again using an entire hand. The next action participants tried was a gripping gesture. After several attempts, only one participant figured out a pinch gesture. In the follow-up interview, many participants noted that they would not be able to figure out the pinch gesture unless they were provided with the instruction.

Table 5.1. Findings from gesture analysis	
Frequency of the gesture participants used to complete the task (%)*	
Menu selection	Press the menu button with an index finger (100%) Press the menu button with the entire hand (82%) Gripping gesture with one hand (52%) Pinch or air-tab gesture with one hand (5%)
Object selection and manipulation (Large size)	Lift the table with both hands (88%) Grab the side of the chair with both hands (84%) Lift the chair with both hands (52%) Push the table using one hand (47%) Gripping gesture with one hand (47%) Pinch or air-tab gesture with one hand (5%)
Object selection and manipulation (Miniature)	Gripping gesture with one hand (82%) Push the object using one hand (29%) Grab the side of the object using both hands (29%)

*Percentages indicate the proportion of participants who used the gesture

When participants first encountered the large-scale furniture items, either with gaze-pinch interaction or touch-grab interaction condition, gripping was not the first gesture participants tried to use. The majority of participants tried to move the virtual table by "lifting" it. In terms of the virtual stool, the first action many participants tried was "grabbing" the side of the stool using both hands. 88% of participants used both hands when they were interacting with large scale objects. The follow-up interview reveals that even after participants learn that they can move the object using only one hand, they preferred using both hands when moving a large object.

> *"Even if it's not real, you think it's furniture. It feels like it should be heavy, and I should be using both hands"*

On the other hand, for the miniature size object, participants frequently used the gripping gesture to pick up the virtual object. The majority of participants used only one hand when they were interacting with a miniature size object.

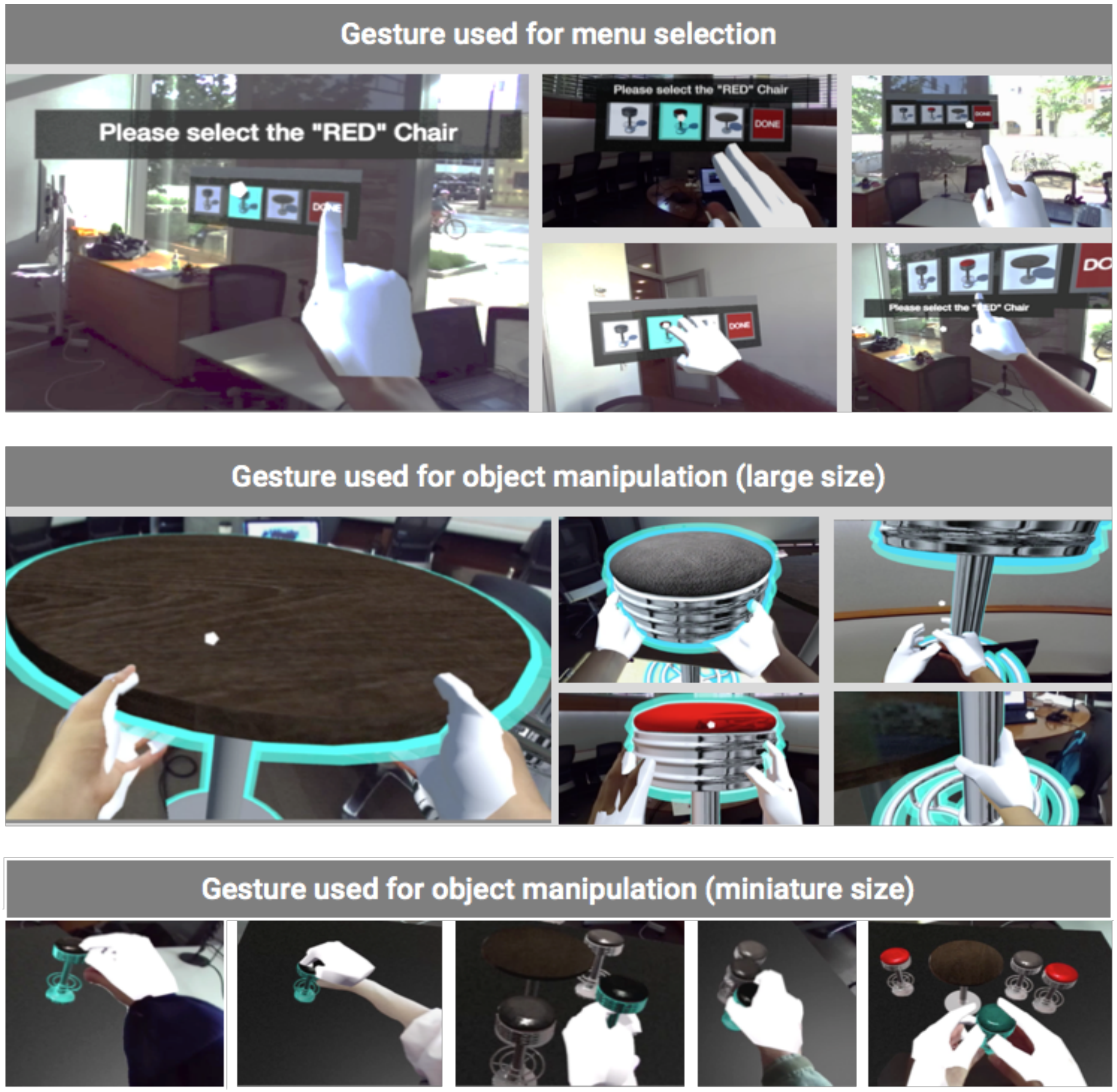


Figure 5.12. Gesture used by participants for menu selection and object manipulation

5.2.2. User Experience

The follow-up interviews reveal the strength and weakness of each interaction techniques in greater depth. Participants also shared their opinions on desired attributes for interaction design and made suggestions on how to make an improvement. Table 5.2 provides a summary of the follow-up interviews. Except for two participants, the majority of participants preferred *worlds-in-miniature* interaction over the other two. Ease of use was what many participants desired the most and many liked the *worlds-in-miniature* for its better usability. Participants frequently described the *worlds-in-miniature* interaction as the “easiest” interaction. Efficiency and accuracy were other main reasons why participants preferred *worlds-in-miniature*. About half of the participants thought *worlds-in-miniature interaction* was just as natural and intuitive as *touch-grab* interaction.

Two participants reported that they liked the *touch-grab* interaction most because the touch and grab interaction seemed more natural than the other two. They described *touch-grab* interaction as a “fun” and “realistic” way to interact with virtual objects. While these two participants thought *touch-grab* interaction was easy to use, more than half of the interviewees reported that gripping gesture was not intuitive enough to figure out immediately. Many of them noted that gripping is not how people would move the large furniture in real-world, which is why it took several attempts to understand *touch-grab* interaction. Although many found touch-grab interaction more demanding than worlds-in-miniature both mentally and physically, about half of the interviewees said they did not necessarily find physical movement taxing or bothersome. With *touch-grab* interaction, users should grab the furniture item and walk around. It naturally involves more physical movement than other two interaction techniques. However, half of the interviewees indicated that they actually liked having to walk around and physical movement was one of the main factors that made touch-grab interaction more real and natural.

Gaze and pinch interaction was participants’ least favorite design amongst three. The most frequently described feeling was frustration. Many noted that gaze and pinch interaction was the most difficult one amongst all, and three interviewees mentioned that they didn’t notice the gaze cursor nor understood the mechanism of gaze input. Participants who previously experienced VR HMDs tends to pick up gaze-pinch interaction quickly. Two participants said that they would like to use gaze and pinch interaction in the future because it allows them easier interaction once they learn how to use it. They especially liked gaze-pinch interaction as it requires less physical

Table 5.2. Findings from a follow-up interview		
User experience with each interaction design		
Worlds in Miniature		
Advantage ❏ Ease of use ❏ Efficient ❏ More precise ❏ Natural	Disadvantage ❏ Not as fun as the other two ❏ Limited view	Sample Verbatims “Miniature one was way easier” “If you are a perfectionist and you want everything in the right position, this is a good way to move furniture” “You don’t really see the large one when you are arranging the small one” “It was easier, but it’s more fun to interact with large objects”
Touch and Grab		
Advantage ❏ Direct interaction ❏ Fun to use ❏ Natural ❏ Physical movement	Disadvantage ❏ Difficult to figure out the grip gesture ❏ Physical movement	Sample Verbatims “It feels more real when you move around and drag the chair across the floor” “I think moving and walking is more intuitive. I don’t mind having to walk. It’s better that way” “Interaction was actually not intuitive, I didn’t know what to do to let the object go"
Gaze and Pinch		
Advantage ❏ Efficient once you figure out ❏ Requires less physical movement	Disadvantage ❏ Less natural ❏ Difficult to use ❏ Have to gaze first ❏ Difficult to select when multiple objects are aligned in the same direction	Sample Verbatims “It’s not realistic” “If someone is not familiar with AR, using eye-gaze won’t be intuitive. I noticed it (cursor) after a while, but I prefer the other one that you can just use your hands. You don’t have to focus on things” “Perhaps, once you figure out, it would not be that difficult, but it was not easy to use at first. I think you definitely need some instruction for this one”
Desired attributes for AR 3D interaction design		
Dynamic interactions	“I hope there are more you can do. Like you can pull, push, or lift, basically do everything that you would do with the real chair and table.” “Perhaps, you can combine all these three somehow or give options to choose. You can pinch, grab and have the mini-size one too.”	
Natural interaction	“You don’t grab the table. That’s not how you move the table in a real-world. When you see a table like this you try to lift it. You put your hands under the top or you just push it. I wish I can do all that in AR too.” “Pinching worked fine when moving the chair, but not for the menu. Can you click it with the finger? That’s what we do on our phone”	
Direct and physical	“I liked when you can directly touch and click the menu. When you see the sci-fi movie, you have all these windows and a virtual control center in front of you. You can still touch it”	

movement and users can still directly interact with a life-scale object. However, except for these two interviewees, everyone else described the gaze and pinch interaction as "least natural" or "not realistic" way to interact with objects. All participants agree that gaze and pinch interaction is not intuitive nor easy to learn for the first time AR users.

6. DISCUSSION

This study examines 3D user interactions for a hear-worn AR device. With an aim to understand how to design user interaction that is intuitive and easy to use, this study compares three widely known interaction techniques: gaze and pinch interaction, touch and grab interaction, and worlds-in-miniature. The finding from the user study suggests two key implications. First, *worlds-in-miniatur*e interaction can be a more effective way to interact with a large virtual object than other popular interaction mechanisms such as Microsoft Hololens' *gaze and pinch* interaction and a conventional *touch-grab* interaction. Second, the findings from the gesture analysis and follow-up interview suggest the critical roles of natural interaction in enhancing learnability—the button should afford to be pressed, a large virtual table should afford to be lifted, and a miniature size model should afford to be picked up.

Worlds-in-miniature interaction stands out amongst three. The findings from the user study indicated that *worlds-in-miniature* interaction significantly enhances efficiency and accuracy in manipulating large virtual objects. The study results show that participants completed the task of arranging multiple furniture much faster with greater precision when using *worlds-in-miniature* interaction. Aside from its benefit for being efficient and accurate, another major benefit of worlds-in-miniature interaction is its ease of use. In the follow-up interviews, many agreed that *worlds-in-miniature* interaction seemed natural and was the easiest one to use among three interaction designs.

In regard to the usability and learnability, it is easy to assume that *touch-grab* interaction would be the most intuitive and easy to use amongst all three given its popularity in VR interaction design. Contrary to the prediction, the finding from the user study showed that participants did not necessarily find *touch-grab* interaction more natural nor intuitive than *worlds-in-miniature* interaction. The gesture analysis and follow-up interviews reveal that "grabbing" is not a natural gesture when interacting with a large object. Almost 90% of participants used both hands to "lift" the large virtual table. It is interesting to note that participants still used both hands even after they learned that they can manipulate the virtual object with one hand. The perceptual property of the object such as weight may influence how users would interact with the virtual object. This is well represented in one of the participants' comments; "*Even if it's not real, you think it's furniture. It feels like it should be heavy."*

Another interesting finding from follow-up interviews is that more than half of the participants didn't find "walking" physically taxing nor bothersome for a room-size environment. The relative merit of *gaze-pinch* interaction as compared to *touch-grab* interaction is that *gaze-pinch* interaction requires less physical movement. With *gaze-pinch* interaction, users can simply stare at the virtual object and move the remote object with the pinch gesture rather than walking toward the object and moving around the space to place the object across the floor. While this *gaze-pinch* approach can be beneficial to manipulate objects in a large space, the conventional way of interacting with the object—grabbing and walking—may provide better usability for a relatively smaller space. The findings of this study indicate that people actually find walking fun and enjoyable rather than bothersome in a room size environment.

Overall, the results of this study suggest critical roles of natural interaction in enhancing usability and learnability. In the remaining of this section, I discuss the design implications based on the study findings and address the limitation of the presented study.

6.1. Design Implications

Applying Worlds-in-Miniature metaphor for AR architecture applications

For the future design of AR architecture applications, applying the *worlds-in-miniature* metaphor may be helpful to support and enrich the user experience. Architecture and construction are one of the most promising application areas for head-worn AR device (Ran & Wang, 2011). Precision and efficiency are critical in such an architecture project. The findings of this study show that *Worlds-in-miniature* interaction allowed a higher level of precision in manipulating multiple objects and was significantly faster than *gaze-pinch* and *touch-grab* interaction.

The major benefits of AR for architects is its ability to let people immerse themselves and visualize the life-scale items in a real-time. However, directly interacting with the large life-scale object can often be difficult. Having a miniature model at smaller scale makes it easier for people to grasp at a glance the entire layout and understand spatial configuration. Unlike *gaze-pinch* and *touch-grab* interaction, that only provide perspective views of the objects, having an additional elevated view of an object from above can help users to judge relative dimensions and the size of objects in the distance (Shashua, 1993). By providing two viewports, perspective view as well as the miniature view, *worlds-in-miniature* allow designers to take advantage of AR features while making interaction still easy to use.

Natural interaction: familiar yet complex at the same time

The findings of the study point to the critical role of natural interaction in enhancing learnability and usability. Even if the object is not real, the participants' gestures reflect their real-life experience of how they would interact with the real object. For large furniture that seems heavy, participants tried to lift it. For a small miniature item that affords to be grabbed, participants tried to pick it up. For a menu button, participants tried to press it. Participants didn't use the same single gesture across different tasks. The gesture participants used largely varied depending on the task and the virtual object they were interacting with.

Such findings provide meaningful implications to the 3D UI designers. Designers often strive to create a “simple” design and find a one single input system that can work across different platforms, frequently worded as a “new metaphor” to interact in a virtual world (Page, 2014). For example, according to Microsoft’s official documentation on their input system (2019) Microsoft Hololens’ air-tab or pinch gesture simulates click action of a mouse with hands. A grip button of VR controllers has been used as the main input for grabbing the virtual object in VR (Oculus, 2018). While using the new metaphor and single input can be beneficial in the longer term once users get accustomed to it, for a novel device such as head-worn AR, it is critical that interaction is familiar and natural enough so that users can easily pick up and learn how to use the new interface. The naturalistic interaction is complex by its nature. In order to enhance the learnability, the design of future 3D user interaction for head-worn AR should take into account the complexity of natural interaction.

Natural movement, hyper-natural virtual worlds

One interesting results to note is that many participants found *worlds-in-miniatur*e interaction natural when the concept itself may seem unfamiliar. Having a miniature copy of furniture is not how people would interact with the objects in a real-world. However, manipulating small objects let people leverage a lifetime physical experience; picking up the smaller object with bare hands. These study findings point to the importance of using natural and familiar movement in a 3D virtual environment. That is, the key attribute to naturalistic interaction is the use of *natural movement*, not the virtual environment itself. This finding may provide insights to answer the age-old question: is naturalism worthwhile?

In discussing naturalism of user interaction, Bowman et al. (2012) used a term, “hyper-natural interaction.” Hyper-natural interaction enhances natural interaction by providing superpower to the users, thereby enabling users to exercise more control over the virtual environment (Bowman et al, 2012). With AR, there are no physical constraints and possibility are limitless, thus there is no need to replicate the real world exactly in this virtual world. According to Bowman and his colleagues’ empirical experiments (2002, 2007, 2009), hyper-natural interaction can significantly enhance performance and usability than an interaction that simply simulates the real-worlds. This study result extends such Bowman’s finding. In order for an AR interface to provide better usability and performance, hyper-natural interaction can be more beneficial than simply mimicking real-world counterparts; however, the interface should allow users to use natural movement.

6.2. Limitation

The evaluation of the interaction designs presented in this study provides a number of significant findings. However, the study findings can not be generalized to across all AR platforms nor to the general population. It is important to note that this study was conducted with participants who have no prior experience with head-worn AR devices. This study specifically examined the learnability of different interaction design, thus the participants tried an AR environment only for the short amount of time. The result from this user testing would not pertain to the longer-term usage of AR. Even for the interaction that appears to be difficult to use at the first glance, it is highly likely people will get better at using it as they perform the same task over a period of time. The results of the study can be largely different in such a case.

The user testing was conducted for the specific task: selecting and manipulating the virtual object within the room-size environment. This study was set up using an optimal play area of

Oculus Rift with two sensors, which was approximately 80 sq ft. For the larger space, the results of the user testing can be different. For example, gaze-pinch interaction could be more beneficial and efficient than touch-grab interaction in manipulating multiple objects in a large environment. The device used for this study also place some limitations on the generalizability of the study results. In creating AR experience, I used a ZED-mini camera with Oculus Rift. A ZED-mini camera provides considerably wider fields of view than Microsoft Hololens, however, it can suffer from latency and parallax issues. Because the cameras are usually not located at the exact same position as users' eyes, the worlds may appear to shift as users move around. Furthermore, the latency of video delivery can cause motion sickness for users (Kytö, Mäkinen, Tossavainen, & Oittinen, 2014). The findings of the study should be interpreted with caution given the limitation of the current state of technology.

6.3. Conclusion

This study compares three widely known interaction techniques: gaze and pinch interaction, touch and grab interaction, and worlds-in-miniature. Overall, the majority of participants found that the *pinch and grab* interaction is most difficult to understand among three interaction designs. Amongst the three, the *worlds-in-miniature* interaction afforded users the most accurate, efficient, and easiest interaction in terms of arranging multiple furniture items. The results of gesture analysis and in-depth interviews reveal the critical roles of natural interaction—an interaction that participants would use with a real physical object—in enhancing learnability and usability. For the novel interface like AR to be adopted quickly by the general population, it is critical that the interface is easy to learn and use. To this end, this study aims to advance the understanding of natural interaction and further provide design suggestions that can aid in developing more intuitive interaction for head-worn AR.

6 GENERAL DISCUSSION

The recent rise of consumer virtual reality hardware has enabled the possibility for the new type of shopping experience. Consumers can virtually examine and try out the products before they purchase them with virtual reality. Numerous articles and retailers predict the bright future, but few have suggested a practical vision for how new shopping experience and development roadmap should look like. The primary goal of this dissertation is to understand how best to use and create virtual reality marketplace that can help consumers to make a more informed decision and have an enjoyable shopping experience. As little is known on how best to use virtual reality for online shopping, this dissertation aims to first explore the potential impact of using virtual reality on the consumer decision-making process. I particularly focus on product choice and purchase intention. Study 1 compares VR to conventional online websites and examines how consumer choice varies depending on shopping modality. Next, Study 2 proceed to explore the underlying factors that may explain the consumer's product choice and purchase intention with VR. Finally, the last study of this dissertation, Study 3, examines the design of 3D user interactions. Based on the findings from Study 3, I suggest the design guidelines that can aid in developing a more natural and intuitive interaction with the virtual product.

Utilizing an interdisciplinary approach, the findings from these three studies make a number of theoretical and practical contributions to the broad academic fields ranging from design, marketing to human-computer interaction. The remainder of this general discussion section addresses the contribution and implications of this dissertation findings. First, I present a summary of findings from three studies. Then, I discuss the theoretical contribution of this dissertation, followed by managerial implication and design implication. The limitation of this dissertation is also addressed in this section.

1. Summary of Three Studies

The purpose of this dissertation is to understand how to best **use** and **create** virtual reality marketplace. The first two studies in this dissertation, Study 1 and Study 2, examine how to best **use** virtual reality and explore in which context virtual reality does particularly excel over conventional shopping modalities. Findings from these two studies suggest that virtual reality can be effective shopping means especially for visually appealing designer goods. The last study of this dissertation, Study 3, examines how to **create** a virtual environment that is easy to learn and use. For the novel interface like VR, it is important to consider ease of use and learnability during the design process. The findings from Study 3 suggest that having a hand-held miniature copy of virtual objects allow more accurate and easier interaction as compared to conventional interaction mechanisms such as gaze-pinch and touch-grab model. The remaining of this subsection discusses the summary of these three studies in greater detail.

1.1. Study 1: the potential impact and perceived benefits of VR

The primary goal of Study 1 is to *identify* the relative benefits of VR shopping and its potential impact on consumer product evaluation. More specifically, this study compares VR to conventional websites and explores how presenting products with an interactive virtual environment influences a choice a consumer makes. In order to better understand the relative merits of VR shopping, I also conducted a follow-up interview and asked participants' subjective opinion on VR shopping. Drawing on the cognitive continuum theory, I posit that when consumers use a website, they are more likely to employ analytic thinking and choose a reasonably priced and functional good. Conversely, when consumers shop with VR, they are more likely to employ intuitive thinking and choose a visually appealing but more expensive product. To examine this proposed effect, I conducted an empirical experiment with furniture goods. The findings of this study indicate that participants better appreciate a stylish and hedonic product when they shop with an interactive 3D environment than with a conventional 2D environment. Furthermore, in the follow-up interviews, participants noted that two major benefits of VR shopping are its informativeness and playfulness. The additional information VR provides such as size and fit and its enjoyable shopping experience were the major motivation to use and purchase a product from the VR store.

1.2. Study 2: factors that influences consumer decision-making in VR

Study 2 aims to *analyze* the underlying factor for consumer's preference for hedonic products in VR in greater depth. Based on Study 1's findings, this study examines the roles of informativeness and playfulness in influencing consumers preference for hedonic product and purchase intention with VR. The goal of this study is two-folded: to examine how various interface design factors (graphics quality, interactivity, and stereo displays) makes VR more informative and playful than conventional online shopping modality; and to understand how the perceived level of informativeness and playfulness influence consumers' preference for hedonic products and purchase intention. In order to examine the interplay between different interface design factors and consumer decision-making process, I created eight different interfaces that differ in the level of graphics quality, interactivity, and display characteristic.

The results of the study provide two meaningful insights. First, interactivity and visual-spatial cues of stereo display significantly enhance perceived informativeness and playfulness; however, the role of graphics quality was found to be less critical for 3D VR environment. Second, informativeness and playfulness influence the purchase decision-making process in distinct ways; a playful interface may enhance consumers' preference for hedonic product benefits, whereas informativeness is a more important explanatory variable for subsequent purchase intentions. The findings of this study highlight the critical roles of informativeness. Consumers are more likely to appreciate the stylish and luxurious appeal of products when products are presented in a playful 3D virtual environment; however, playfulness alone could not lead consumers to a subsequent purchase. Informativeness is the bedrock of online shopping that will ultimately drive consumer's purchase intention.

1.3. Study 3: designing 3D user interaction

The last study in this dissertation, Study 3, aims to *design and evaluate* different interaction techniques in a 3D virtual environment. Unlike the previous two studies that mainly explore the use of a VR device, in this study, I examine the design of augmented reality (AR) interface using the latest technology. AR interface allows users to visualize a virtual object in their own house, and thus, can be more informative and beneficial than VR in the context of furniture shopping.

The major goal of this study is to understand how to design a 3D user interaction that is easy and intuitive to use for a head-worn AR device. I particularly focus on interaction using hand inputs. This study compares three widely-used interaction techniques: 1) touch and grab interaction, 2) multimodal interaction using gaze and pinch gesture, and 3) Worlds-in-Miniature technique. Furthermore, in order to identify interaction that may be more intuitive than these three interaction designs, I also conducted a follow-up interview and analyzed the gesture participants used when they first encountered the virtual object.

A comparison study reveals the strengths and weaknesses of each interaction technique. The result of a user study indicates that the worlds-in-miniature technique provides better usability and allows users to achieve a higher level of accuracy in manipulating multiple virtual objects. Contrary to the prediction, the conventional touch-grab interaction was not considered as natural nor intuitive by many participants. Further analysis of participants' gesture and follow-up interview reveals that *grabbing* is not a natural way to interact with large furniture items. Instead, the visual clue and perceptual property the objects largely determined the gesture participants used. For example, for the large tabletop that appears to be heavy, participants tried to lift it using both hands rather than grabbing it. The results of the user study suggest the critical roles of visual clues and corresponding natural mapping in designing 3D user interaction.

2. Theoretical Contribution

The findings of this dissertation make a number of theoretical contributions to broad academic fields, mainly the field of marketing, design and human-computer interaction (HCI). In this subsection, I discuss how the findings of three studies contribute to advance the knowledge in these academic fields.

2.1. The interplay between the shopping environment and consumer decision-making

The findings from Study 1 and Study 2 shows that the use of virtual reality can have a significant impact on consumers' product evaluation and purchase intention. These two studies represent a few academic research that examines the interplay between virtual reality shopping environments and consumer decision-making. The recent development in consumer-level virtual reality devices has sparked academic interest in virtual reality shopping, but prior works on virtual reality shopping are rather limited, partially due to the relative novelty of virtual reality technology for general consumers. Several researchers have examined the use of virtual reality in the marketing context and explored its effectiveness, but none of the prior works have looked into the impact of virtual reality shopping on consumers' product choice. To the best of my knowledge, Study 1 and Study 2 in this dissertation are the initial attempts that examined the interplay between virtual reality shopping environment and consumers' hedonic preferences.

The main theoretical contribution of this dissertation is the expansion of the scope of research that examines the interplay between the shopping environment and consumer behaviors. By far, the most popular research topic in the marketing literature, with respect to the research into virtual reality, has been a consumer's willingness to adopt the virtual reality technology (e.g. Kim

& Forsythe, 2008; Pantano & Servidio, 2012; Yim, Chu & Sauer, 2017). Previous research into virtual reality and consumer behavior predominantly used the Technology Acceptance Model as their research frameworks. While applying the technology acceptance model (TAM) can provide meaningful insights into understanding how consumers are going to adopt the new VR technology, one of the critics to note regarding TAM is its lack of practical value (Chutter, 2009). More specifically, TAM mainly explains the relationship between perceived ease of use, usefulness, enjoyment and consumers' willingness to adopt the technology and rarely addresses "what" makes the new technology ease to use and useful (Benbasat & Barki, 2007).

This dissertation takes a further step beyond examining the relationship between these variables—perceived usefulness, enjoyment, and ease of use—and consumer behavior, and explores external variables that make VR shopping more useful, enjoyable and easy to use. Study 2 in this dissertation investigated how various interface design factors—graphics quality, interactivity, and display types—work together to make VR shopping more useful and enjoyable, namely informativeness and playfulness of the VR store. Study 3 in this dissertation compared three different interaction designs to find out the interface that is easy to use. Building on prior works on technology acceptance model (Davis et al., 1989; 1992; Verkatesh & Davis, 2000), hedonic and utilitarian product benefits (Chitturi et al., 2008a; Dhar & Wertenbroch, 2000; Roggeveen et al., 2015), interplay between virtual reality and consumer behavior (Kim & Forsythe, 2008; Suh & Lee, 2005; Yim et al., 2012; Yim et al., 2017) , the findings from Study 2 and 3 provides new knowledge of what external variables can contribute to enhancing the perceived level of ease of use, usefulness, and enjoyment for using virtual reality.

2.2. Distinctive roles of informativeness and playfulness

The distinctive roles of playfulness and informativeness are major contribution this dissertation research adds to the preceding marketing and HCI literature. The findings of Study 2 shows that informativeness and playfulness influence the purchase decision-making process in distinct ways; a playful interface may enhance consumers' preference for hedonic product benefits, whereas informativeness is a more important explanatory variable for subsequent purchase intentions. A dichotomy of functional and hedonic dimensions of an interface—informativeness and playfulness in Study 2—has been a fertile research domain in marketing and HCI research (Davis, Bagozzi, & Warshaw, 1992; Ha & Stoel, 2009; Kim & Forsythe, 2008). However, the relative impact of informativeness and playfulness on the different stages of purchase decision making has received relatively less attention. Study 2 of this dissertation represents an initial attempt to examine distinctive roles informativeness and playfulness.

In examining the impact of informativeness and playfulness, this dissertation takes a unique methodological approach. In designing research model and analyzing the data, the use of a structural equation modeling (SEM) has been the most common approach in the prior marketing and retailing literature (Kim & Forsythe, 2008; Yang et al., 2009; Yim et al., 2017). The use of structural equation modeling can be effective to test the role of informativeness and playfulness as a mechanism, but such an approach can be limiting for two reasons: 1) the measurement would primarily reflect individuals' perception of "one single" interface, 2) thus do not explain how different level of informativeness and playfulness would have a real impact on consumers' decision making. To be more specific, the most common approach in previous marketing and retail literature is to show one single virtual reality environment to participants and ask them to indicate their willingness to use VR shopping (e.g., Kim & Forsythe, 2008; Pantano & Servidio, 2012). Such an approach offers little explanatory power because the impact of informativeness and playfulness were analyzed based solely on one single stimulus, and thus, didn't really reflect the different level of informativeness of virtual interface. In Study 2, I explore the impact of informativeness and playfulness by manipulating different interface features—such as interactivity, graphic qualities, and stereo displays. This approach can provide more practical value in interpreting study results.

3. Managerial Implication

The findings from this dissertation can help online retailers to better understand how to effectively use virtual reality. This subsection discusses practical implication and managerial relevance of these study findings.

3.1. VR can be an effective shopping means for hedonic products

Companies have explored various forms of VR shopping, yet there is little known on how to best utilize this brand-new technology for marketing practice. From a managerial standpoint, it is worth examining whether using virtual reality would influence the consumer-decision outcome and can provide additional merits to conventional websites. The results of Study 1 and 2 suggest that the use of VR can be particularly more helpful when selling the experiential luxurious product. The results of empirical studies show that consumers are more likely to appreciate the stylish and luxurious appeal of products when products are presented in an interactive 3D virtual environment than with still images and videos. The chance of choosing hedonic products over utilitarian product got significantly increased when participants used VR shopping environment.

Such findings from Study 1 and Study 2 are particularly relevant in today's rapidly developing e-commerce world. U.S. Online retail sales have been growing exponentially over the past decades, and online sales now account for almost 15% of total retail sales (U.S. Commerce Dept., 2019). However, large-scale luxury or designers goods represents one of the toughest product group to sell online, with many designers brand still struggling to penetrate into the e-commerce market. The findings from this dissertation suggest that use of VR can help consumers to better appreciate the visual appeal of the product. Being able to more directly interacting with the life-scale product can mitigate the perceived risk associated with online shopping and provide more confidence to shoppers in purchasing expensive designer goods.

3.2. Informativeness is the bedrock of VR shopping

Before companies make investments to create a virtual reality shopping application, retailers might like to know the effectiveness of VR in increasing sales. The findings from Study 2 shows that the use of virtual reality can significantly enhance the purchase intention. Purchase intention, of course, is different than actual purchasing; however, a great deal of previous marketing research has shown that there is a strong correlation between an actual sale and purchase intention, suggesting that purchase intention can be a valid measure to predict sales (Morwitz et al., 2007a). In short, the findings of this dissertation suggest the possibility that the use of VR can be an effective means to increase online sales.

However, retailers should keep in mind that informativeness is the bedrock of virtual reality shopping that will ultimately drive consumer's purchase intention. The findings from study 2 suggest that consumers may choose hedonically superior products when virtual reality store provides a playful and enjoyable experience, yet if a virtual reality store lacks informativeness, such preference for the hedonic product would not proceed to the purchase intention. Informativeness of the VR store is the key factor that can lead to consumers' purchase intention. The results from study 2 also suggest that more direct interaction with the product, as well as the visualization of spatial information, are critical design factors that can enhance the informativeness of online furniture shopping. All these findings can provide meaningful implications for retailers in utilizing and creating a virtual reality store.

4. Design Implication

The findings from this dissertation can help designers and UI researchers to better understand how to create 3D user interaction that is easy to learn and use. This subsection discusses the design implication this dissertation provides.

4.1. WIM is an effective and efficient way to interact with virtual furniture products

The results from Study 3 suggest that applying the *worlds-in-miniature* metaphor can support and enrich the user experience for AR furniture shopping application. Study 3 compares three widely known interaction techniques: gaze and pinch interaction, touch and grab interaction, and worlds-in-miniature. The finding from the user study suggests that *worlds-in-miniatur*e interaction can be a more effective way to interact with a large virtual object than other popular interaction mechanisms such as Microsoft Hololens' *gaze and pinch* interaction and a conventional *touch-grab* interaction. The major benefits of AR for architects is its ability to let people immerse themselves and visualize the life-scale items in a real-time. However, directly interacting with the large life-scale object can often be difficult. Having a miniature model at smaller scale makes it easier for people to grasp at a glance the entire layout and understand the spatial configuration. Furthermore, having an additional elevated view of an object from above can help users to judge relative dimensions and the size of objects in the distance. The findings of Study 3 show that *Worlds-in-miniature* interaction allowed a higher level of precision in manipulating multiple objects and was significantly faster than *gaze-pinch* and *touch-grab* interaction. By incorporating *worlds-in-miniature* metaphor in AR interaction design, designers can maximize usability and enrich the overall user experience.

4.2. Benefits of naturalistic interaction

The findings of Study 3 can provide insights in answering the age-old question in HCI research: is naturalism worthwhile? There has been a continued debate about whether it is beneficial to simulate the real-world components as closely as possible in the virtual worlds. On the one hand, naturalistic interaction that mimics the real-worlds enables users to easily understand how to interact with the virtual object, minimizing the learning curve. But, on the other, simulating the exact real-world also means that user interactions are affected by unwanted constraints of the real world. For example, if interaction only allows users to use their natural grabbing gesture to interact with the virtual object, users can't access the object that's beyond their arm's reach.

Studies on naturalistic interaction have produced remarkably inconsistent results. Some studies have found that naturalistic interaction results in better performance and usability (Wikes & Bowman, 2008; Ragan, Kopper, Schuchardt, & Bowman, 2012), while others show that naturalistic interaction can be detrimental to performance and usability (Kytö et al., 2018; Pausch, Burnette, Brockway, & Weiblen, 1995; Poupyrev et al., 1996). Although the difference across experimental design and interaction tasks preclude drawing any generalizable conclusion that can reconcile the disparate findings, it is clear that there is a factor that moderates the effect of naturalism on usability and performance.

The findings from Study 3 may provide insights into finding the boundary point that makes natural interaction more effective or not. The user testing results from Study 3 show that world-in-miniature interaction provides better usability and learnability than other conventional touch and grab interaction design. Interestingly, the concept of worlds-in-miniature itself—having a hand-held miniature copy of virtual object—may seem unfamiliar to a lot of users; yet, many participants found worlds-in-miniature interaction natural and easy to figure out. Having a miniature copy of furniture is not how people would interact with the objects in a real-world. However, manipulating small objects let people leverage a lifetime physical experience; picking up the smaller object with bare hands. This finding provides meaningful insights: that is, the key attribute that makes interaction usable and natural is the use of *natural movement*, not the virtual environment itself. For a novel interface like VR/AR, this finding can be especially important for HCI researchers in designing a new naturalistic interaction.

5. Limitation

The findings of this dissertation provide a number of theoretical, managerial, and design implications in understanding the use of virtual reality for online shopping. However, all of these results were obtained with specific sample populations, with the specific product group, and using specific VR/AR devices. Therefore, the results of the study may not be generalized to all population, all consumption scenarios, nor across different VR/AR device platforms. This subsection discusses the limitation of this dissertation. The limitations addressed in the remaining of this subsection are categorized into 1) limitation in recruitment strategy; 2) limitation in the choice of the target product, 3) limitation in the study setting, and lastly 4) technological challenges and limitations of VR/AR.

5.1. Recruitment Strategy

An important caveat that should be mentioned first is the recruitment strategy. Each study in this dissertation used different samples as experiment participants, that includes college students, Amazon Mechanical Turk users (MTurk), and young adults recruited from the Madison area. In Study 1 and Study 3, I used convenience samples of college students. College students are an important target audience and main consumer group for innovative technology such as VR/AR, thus, serves the purpose of the studies well. Study 3 mainly addresses the usability of different AR interaction designs, and a great deal of previous studies shows that using college students for user testing can provide meaningful insights for UI designers and researchers. Thus, for Study 3, college students can represent an appropriate target group for an experimental study.

However, Study 1 examines the use of VR for furniture shopping, and college students may not be the accurate representation of the target group in such a case. Undergraduate students are less likely to have experience with furniture shopping, hence can pose a problem for study's external validity. The latest Consumer Reports shows that millennials, whose age currently ranges from 21 to 37, are the largest consumer group in the U.S. furniture and home goods markets (Consumer Reports, 2018). In order to address these external validity issues, in study 2, I recruited young adults whose age falls into the ages of millennials.

In Study 2, I used two recruitment strategies: online recruitment with Amazon Mechanical Turk and local recruitment in the Madison area. The primary purpose of using Mturk was to tap into a more diverse population that better fits the target consumer segment for furniture shopping than college students (Minton, Gruel-Atay, Kahel, & Ring, 2013). I carefully screened local participants to minimize demographic heterogeneity. A number of prior literature that compared Mturk to the traditional face to face survey methods found that the results across the samples for the same task were almost indistinguishable (Casler, Bickel, & Hackett, 2013).

However, others have wondered about the reliability of Mturk samples. Studies have found that online survey participants are less invested or motivated than traditional lab participants (Gosling et al, 2004). Although I didn't find significant differences between attention level across survey samples in Study 2, it is possible that Mturk participants simply choose the neutral answer every time to finish the survey as quickly as possible. If the answers are provided this way, the results from Mturk survey may be less accurate or truthful than the results from local VR participants. It is also possible that VR participants hesitate to express their purchase intention because the indication of "I would like to order the product" could appear more valid when they are communicating with a surveyor face-to-face than filling out an anonymous online survey. Mechanical Turkers, on the other hand, may have responded in agreement, which frequently happens when respondents are less engaged (Wessling, Huber, & Netzer, 2017). Despite this possibility, I found that the enhanced level of informativeness and playfulness significantly correlates to heightened purchase intention, suggesting that the results of Study 2 could have been even stronger if I have used a single recruitment pool.

5.2. Choice of Product: Furniture

Another important concern that should be mentioned is the choice of the product; furniture. I believe the study findings from this dissertation can yield meaningful implications for ranges of product categories, especially when size and dimensions are critical factors for purchase (i.e., home electronics, kitchen appliances, luggage and more). However, the study results would not apply to all types of products.

For example, the study results on the importance of graphics quality, interactivity, and visual-spatial cue in Study 2 show that graphics quality played less critical roles in enhancing informativeness and playfulness of the VR store. This results could be different if the study was conducted with other product items than furniture. Fashion apparel would be a good example for counter-arguments, as the realistic look of the product can be a more critical concern when shopping for clothes, whereas visual-spatial information such as size is relatively more important for furniture (Gallino & Moreno, 2018). Findings of study 2 on hedonic valuation would not be applicable to utility-oriented goods such as computer hardware and books. However, I did not address these utilitarian goods in this study 2, because a prior study has investigated the influence of product category on VR shopping in greater depth (Suh & Lee). Moreover, online sales for books and hardware are already bigger than offline sales (Statista, 2017), thus the study findings would be less meaningful for these goods.

Large furniture items were the focus of Study 3 as well. The interaction design presented in Study 3 mainly addresses the interaction with large furniture items. Thus, findings from Study 3 can not be generalized to other interaction scenarios. For example, the result of Study 3 suggests that worlds-in-miniature excelled other conventional interaction techniques; but, it is highly likely that this result would not hold true for other interaction scenarios such as interacting with smaller objects or much bigger objects than furniture. In summary, the findings from all these studies may not be applicable to other product categories, hence the results should be interpreted with caution.

5.3. Study Setting: Lab Experiment

All studies presented in this dissertation were conducted in a controlled laboratory setting. In Study 1 and Study 2, the study subjects were not engaged in an actual purchase but "simulating" shopping. Subjects tend to pay less attention to the shopping environment when they are merely simulating purchase (Burke, Harlam, Kahn, & Lodish, 1992a). The results of Study 2 suggest that informativeness significantly enhances the purchase intention in VR, but it is highly possible that informativeness would play an even more crucial role in actual shopping condition.

Whether the results on consumers' enhanced purchase intention and hedonic preference with VR would transfer to the actual purchase remains questionable as well. However, the previous study that compared the actual sales and purchase intention suggests that purchase intention can be used as an effective predictor for actual sales. A number of researchers demonstrate that there is a strong correlation between purchase intention and actual sales and further claims that the findings from the lab experiment can predict how consumers would behave in a real-world (Carrington, Neville, & Whitwell, 2010; Morwitz, Steckel, & Gupta, 2007b).

In the lab experiment setting, participants only interacted with AR devices only for a short period of time. In Study 3, participants interacted with the AR interface for 45 minutes on average, at most an hour. Thus, questions of generalizability arise in terms of utilizing proposed interaction mechanisms in real-world contexts and for a long-term. Whether the superiority of worlds-in-miniature interaction over other conventional interaction mechanism demonstrated in this Study 3 could be obtained in less controlled environments remains unanswered. The result from the user testing would not pertain to the longer-term usage of AR. In order to examine the generalizability of the findings, future works would need to explore the uses of different 3D user interaction techniques in a real-world scenario for the longer time span.

5.4. Technical Challenges and Limitation

Technological challenges and the limitation of the current virtual reality devices are another critical concern. In discussing the generalizability of this dissertation findings, the important thing that should be addressed is the slow pace of adoption of VR. Despite the spike in the investment in the VR technology in the last couple of years (Perkins Coie, 2018, 2019), VR device is still not commonplace in an average consumer's everyday life. From the consumers' point of view, the expensive and bulky hardware is the biggest obstacle to mass adoption of VR technology (Perkins Coie, 2019). From the retailers' point of view, developing VR shopping applications require extra investment because it uses additional bandwidth, requires the creation of 3D models and development of the application, all of which can be time-consuming and expensive.

Currently, the main application area of VR has been gaming (Perkins Coie, 2018, 2019). In the latest survey by Perkins Coie, respondents found lack of compelling contents other than gaming (24%), along with poor user experience (26%) are the biggest obstacle for broader adoption of VR/AR. These survey results indicate that, in order to see the faster growth of VR, the development of more useful contents and improvement on user experiences are the upmost important issue. This dissertation addresses both of these concern. Throughout three studies, I aimed to explore how to better use and create virtual reality in order to help consumers to make a more informed decision and enjoyable shopping experience. This dissertation can be a key first step toward the venture of developing useful VR shopping applications, that I believe can significantly help the broader adoption of VR.

7. CONCLUSION

The successful integration of virtual reality(VR) and augmented reality(AR) into retail can drastically transform the current online shopping experience. The interactive life-scale size products in VR/AR can help shoppers to make a more informed decision and have an enjoyable shopping experience when purchasing the product online. This dissertation investigates **how to best use and create a virtual reality marketplace.** In a series of three studies, I examined in which contexts virtual reality can particularly excel conventional online shopping using websites, and explored design solution in developing a 3D user interaction that is easy to use and learn. In Study 1, I focused on identifying the potential impacts of using VR on consumers' product choice. In Study 2, I investigated the underlying factors that can explain the impact of VR on consumers' product choice and purchase intention. Finally, in Study 3, I explored the designs of 3D user interaction that can enhance the learnability and usability of AR furniture shopping to the novice AR users.

The findings across three studies provide insight into answering the aforementioned research question: how to best use and create a virtual reality marketplace. Results from Study 1 and Study 2 show that virtual reality can be a particularly effective shopping means for shopping experiential and hedonic products. This finding is especially meaningful for online retailers because luxury designer goods represent one of the toughest product group to sell online. The successful use of virtual reality can drastically help retailers and consumers in purchasing luxurious and experiential goods by mitigating perceived risk associated with purchasing an expensive product online without examining it in person. The findings from Study 3 highlights the critical roles of visual clues and corresponding natural interaction in enhancing learnability and usability.

Based on the study findings, I provided design suggestions that can aid more natural and intuitive interaction with a virtual product.

From observation and analysis of user testings, I suggest that designing intuitive 3D user interaction should reflect the complexity of natural interaction. In designing a new interface, designers often strive to create a “simple” design that can work across different platforms and aim to find a single input that corresponds to the system users are already familiar with. Microsoft Hololens is an exemplar of such contemporary design trends; its head-gaze cursors mimicks mouse cursor and its air-tab gesture simulates the click action of the mouse. Although the concept itself is abstract and unnatural, such a simpler input system has been considered to be beneficial in achieving accuracy and efficiency (Galitz, 2007; Venkatesh, 2000). However, Study 3’s finding on the superiority of worlds-in-miniature shows that there is another way to achieve accuracy and efficiency while still keeping the natural feel. Having a hand-held miniature model significantly enhanced efficiency and accuracy in manipulating large furniture items as compared to the case when participants used a Microsoft Hololens’ gaze and pinch interaction technique. The key to the naturalistic interaction was the use of *natural movement*, using a gesture that reflects how people would interact with the real object.

Natural interaction is complex and dynamic by nature. The findings from Study 3 point to the critical roles of visual clues and corresponding natural interaction. Even if the object is not real, the participants’ gestures reflect their real-life experience of how they would interact with the real object. For large furniture that seems heavy, participants tried to lift it. For a small miniature item that affords to be grabbed, participants tried to pick it up. For a menu button, participants tried to press it. Participants didn’t use the same single gesture across different tasks. The gesture participants used largely varied depending on the task and the visual shape of the virtual object. Such findings provide meaningful implications to the 3D UI designers. While using the new metaphor and single input can be beneficial in the longer term once users get accustomed to it, for a novel device such as head-worn AR, it is critical that interaction is familiar and natural enough so that users can easily pick up and learn how to use the new interface.

Technology that seemed like science fiction not so long ago now is just around the corner, enabling numerous possibility to reshape the current retail industry. This dissertation takes the key first step toward a better understanding of the potential impact of VR into the realm of online shopping. Yet, more questions remain to be answered. The remaining of this section discuss how future work can move beyond and successfully integrate VR into consumers' shopping experience.

7.1. Future works

7.1.1. Expand the study findings

The presented studies in this dissertation have a number of limitations that can be addressed in future works. The findings from three studies only examined the impact of VR in the controlled laboratory environment. For example, studies in this dissertation only "simulated" virtual shopping rather than examining actual purchase behavior. In order to enhance the external validity of study findings, future works can examine VR shopping behavior in a more realistic setting. In previous marketing literature, several researchers made attempts to conduct empirical studies in a realistic shopping environment by creating a mock-up store and collect actual sales data (Baumstarck, 2008; Chandon, Hutchinson, Bradlow, & Young, 2009b), conducting field experiments in actual stores (Hui, Inman, Huang, & Suher, 2013; Inman, Winer, & Ferraro, 2009; Russell & Petersen, 2000), or taking a more qualitative approach and observe participants everyday shopping experience (Trijp, Hoyer, & Inman, 1996; Wolfinbarger & Gilly, 2010). Instead of inviting participants to the laboratory environment, future works can examine consumers' behavior by launching mock-up stores on a public platform, such as the Google Play app store or Steam VR, and collect data in more real-world contexts.

The future works can also explore the longer-term impact of VR on consumers. One of the promising research topics is brand recalls. Brand recall refers to the extent to which customers are able to elicit a brand name from memory when prompted by an external stimulus (Steadman, 1969). Brand awareness has been a popular research domain in marketing and advertising research. With VR, more direct interaction with the product can offer a more realistic consumption experience in an immersive and natural setting than traditional media or a conventional video-game environment, which in turn, can enhance the engagement with the product and brand recall.

In reference to the longer-term impact of VR on usability and learnability, future works can examine the learning curve of different interaction design. This dissertation only examined learnability of different interaction design, which is different than learning curve, thus the participants tried an AR environment only for the short amount of time. The learning curve is a representation of the rate of learning something over time with repeated experience. Even for the interaction that appears to be difficult to use at first glance, it is highly likely people will get better at using it as they perform the same task over a period of time. The usability with the first-time users can provide meaningful insights into understanding user experience; however, a usability study on the first time user experience sheds little light on usage behavior after the onboarding stage (Preece et al., 1994). Future works can explore more complex user flow such as factor influencing frequency of usages, and users' retention of the VR/AR technology by conducting more in-depth and lengthier studies.

7.1.2. Moving beyond: ideas for future research

In addition to future works spanning from this dissertation's finding, a number of interesting questions can be posed for designing more effective virtual reality marketplace. This section presents ideas on how future work can move beyond examining the impact of VR on consumer decision making with furniture shopping.

Defining interactivity

In measuring interactivity, informativeness, and playfulness, this dissertation used the questionnaire items that have been developed by previous research. These terms have been widely used in many academic disciplines, however, the term itself is vaguely defined. This is particularly true for the case of the term interactivity. Interactivity has been often mentioned in online marketing research but rarely operationalized. Furthermore, interactivity has been widely studied in communication research thus most definition has focused on the process between a perceiver and an interface, instead of emphasizing contents (McMillan & Hwang, 2002). For example, the most common approach to measure interactivity is to use a questionnaire on interpersonal communication (e.g., enables concurrent communication) and information control (e.g., helps me to gather useful information), which are more related to outcomes of interactivity than to particular interaction design. To date, research on perceived interactivity has been primarily conceptual and not contents-specific, hence providing limited implications for designers and practitioners. The future work can reexamine the term interactivity and develop new operational measurement scales.

Other product: travel, hospitality, and more

Another productive area for research is to explore the use of VR for the travel and hospitality industry. According to the latest survey by Google (2019), 74% of travelers consider the internet as the most important source for travel planning. Virtual reality enables potential guest and event planners to better understand the character and atmosphere of the environment and figure out the size of the event spaces without needing to travel to the actual location. Given the promising future of VR in the travel and hospitality industry, future works can address how to effectively design VR experiences to help future guest easily navigate and examine multiple sites or properties.

Include social factors in designing VR stores

Shopping is often a social activity (Arnold & Reynolds, 2003). Arnolds and Reynold (2003) found that many consumers often visit stores with family and friends and socialize with others while shopping, which they refer to as “social shopping.” With the rise of the mobile device and rapid growth of online shopping, social shopping is now extending beyond the brick and mortar store and move into online worlds. Using a real-time communication platform, such as social media, consumers communicate and aggregate information about products, prices, and deals and share their thoughts with each other. Recent advance in multi-user VR technology allows people to communicate real-time in the virtual worlds. Now, retailers and designers can host guided walkthroughs of virtual space, extending the concept of personal shopping or guided tour. Multi-user collaboration features can significantly change the way consumers share their thoughts and opinion online as well. Future works can examine how multi-user VR technology can shape social shopping trends in online.

7.2. Final Remarks

“Whatever the goal of the web site designers, in order to be sure that the desired effect is being induced, they have to test the document, with all of the planned elements included. The chances are, in this new medium of communication, that different combination of different elements will produce unexpected results.”

-May, Sundar, and Williams (1997, p.9)

To date, especially for the new medium such as VR/AR, the combined effect of different design factors has been considered difficult to predict. In this dissertation, I aimed to provide a more comprehensive understanding of VR and consumer behavior. I tried to understand consumer experience by listening to their voice, observe their behaviors, and examine the potential impact of VR on consumer behaviors by creating different prototypes and manipulate different design elements. This dissertation mainly addresses the potential impact of VR on product choice, purchase intention, along with the 3D user interaction with the furniture products. The sequence of my research process in this dissertation demonstrates my strong desires to make a meaningful contribution to the real world. My long-term goal is to investigate how to use emerging technology to improve the current online shopping experience, and thereby help consumers to make a more informed decision. I aim to pursue this line of research in the years to come. The outcome of my research on emerging technology will make contributions in the broad academic fields; design, marketing, and human-computer interaction.

APPENDIX

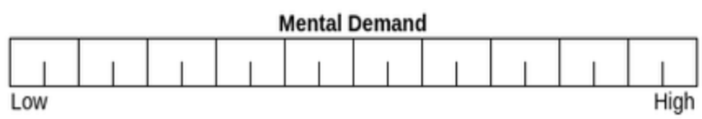
STUDY 2

Choice options (Four chairs and four desks)

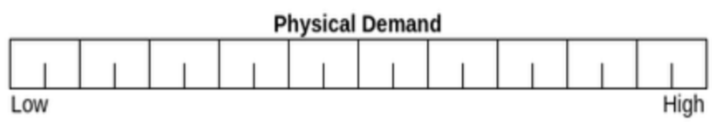
STUDY 3

NASA-TLX Questionnaire

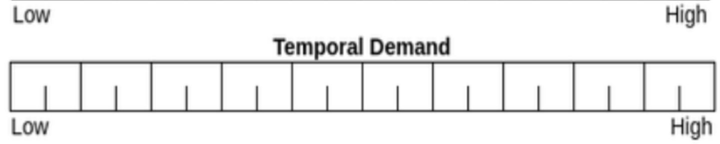
Mental Demands
How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?



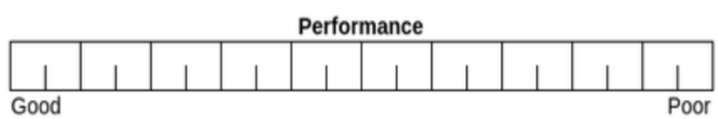
Physical Activity
How much physical activity was required? Was the task easy or demanding or strenuous?



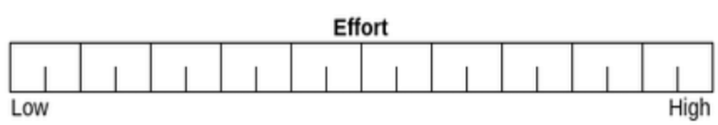
Temporal Demand
How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?



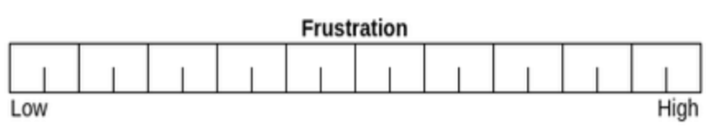
Overall Performance
How successful were you in performing the task? How satisfied were you with your performance?



Effort
How hard did you have to work (mentally and physically) to accomplish your level of performance?



Frustration Level
How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?



System Usability Scale, Enjoyment, and Naturalism

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently.	1	2	3	4	5
2. I found the system unnecessarily complex.	1	2	3	4	5
3. I thought the system was easy to use.	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5. I found the various functions in this system were well integrated.	1	2	3	4	5
6. I thought there was too much inconsistency in this system.	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
8. I found the system very cumbersome to use.	1	2	3	4	5
9. I felt very confident using the system.	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5
11. It was fun to use this system	1	2	3	4	5
12. I found it enjoyable to interact with the items with this augmented reality system	1	2	3	4	5
13. This augmented reality system responded my specific needs quickly and efficiently	1	2	3	4	5
14. Interaction with a virtual object seems intuitive and natural	1	2	3	4	5
15. Interaction with a virtual object was similar to how I would interact with an object in a real-world	1	2	3	4	5
16. Interaction with a virtual object felt familiar	1	2	3	4	5

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