Is it Worthwhile Going Immersive? Evaluating the Performance of Virtual Simulated Stores for Shopper Research

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Preface

Looking at it in hindsight, writing this section of my dissertation was probably the most difficult part. I never used to be a person that tended to write anything about their personal matters. However, after getting this far in my journey to achieve a doctorate degree, I feel it is important to share some thoughts that accompanied me during the past years. Over these years I read many prefaces in dissertations about PhD students' very own ambitions to embark on the journey of achieving this ultimate academic goal. Most of them reported that they always dreamed of and had the desire to earn this academic title. Their lives seemed to be predetermined from the early beginning of their academic life. Research and gaining knowledge was what motivated and drove them. Academic merit the essence of their lives. These were life stories that are in stark contrast to what I ever had in mind. Doing a PhD was unthinkable for me but eventually life persuaded me to change my plans for good.

An unexpected move to a new country for a relationship suddenly opened very new avenues in my life and the pieces started falling into place. When looking for work in my new home in Palmerston North, New Zealand I made my way to Massey University campus and knocked on the door of my current PhD supervisor, Dr Judith Holdershaw. Although Judith did not have any work for me at that time, this visit was when the foundation for a, from my perspective, fabulous supervisor-student relationship was layed. Thanks to Massey University's decision to award me with a doctoral scholarship, I was able to commence my PhD studies just a few months after my initial contact with Judith. She also was the person who convinced Prof Malcolm Wright, who knew very little about me, to act as my primary supervisor. Judith and Malcolm, I like to thank both of you for your trust in my capabilities and your extraordinary support. You are not only academically brilliant but also provided all of your students with so much emotional support and always had a smile and some nice words for them. I never had a time during my PhD when I felt treated unfairly or left alone. You made my PhD journey a throughout positive experience and I will never forget the time we had together. Especially Malcolm, you deserve an honorary mention for believing in the potential of our VR project and the extra support you provided, financially as well as academically. I really appreciate the time and effort you put into all of this and really enjoyed our time together at the various

VR showcases. And thank you for doing the improvised pitch at the B:HIVE, I am still getting nervous when thinking about that moment. Thank you so much for everything!

Despite all the worries I might have had about my future in an earlier stage of my life, everything turned out just fine for me. However, all the achievements I made so far would not have been possible without all the great people that supported me along the way. Be it relatives, friends or colleagues. Hence, I like to take this opportunity to give you the merit you all deserve. I like to start with my parents, who made many sacrifices and had to go through several periods of hardship to make sure that my brother and I got provided with the necessities to succeed in life. They are the people that shape our personalities and who work hard to equip us for all the challenges that life has for us. Parents give us the tools, in form of education and love, that allow us to become responsible agents and valueable members of society. I hope you are proud of the human-being you raised and I wanted to let you know that you certainly can be proud of yourself. Next, I like to remember my grandparents, who are unfortunately not among us anymore and cannot witness this moment of success for me. Especially my granddad Hans, who was to kindest person I ever met in my life. I hope both of you rest in peace and that you would have been proud of your little grandson, I will never forget you, Oma and Opa.

I now like to thank my friends Noor, Barirah and Leena for always having an open ear for me and a warm meal to fill my hungry student tummy. Simon, my study buddy, I had endless hours of political discussions with in our office, to the detriment of our room neighbour. My friend Andrew for being such an awesome flatmate and the great fun we had in the evenings in our little livingroom at home. Thies Lühmann, my old friend from Germany who contributed invaluable software development work for the virtual store simulation we invented for the project. Massey Ventures Ltd. and Consumer Insights Ltd. without whose financial contributions all the data collection for my project would not have been possible. Thank you, Mark, Emma and Ro-Ann for making working on Palmerston North campus such a nice and joyful experience for me. I still miss our chats over lunch at Indian Summer. My gratitude also goes to all the remaining staff at Massey University that are unmentioned here. You are a great bunch. Please, never change and be assured that you will always have a place in my memory. Thank you, New Zealand for welcoming me and providing me for so many great opportunities. God bless you and stay the great country that you are.

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Abstract

Advances in simulation technology offer the possibility of more authentic shopper environments for virtual store experiments. Criticisms of subjective measures of consumer behavior previously led to the use of test markets or simulated stores for consumer experimental research. As cost implications made such experiments unavailable to the wider market research community, virtual simulated stores (VSSs) were developed as an alternative. However, the adoption of VSSs has been slow as traditional desktop-operated VSSs do not provide an authentic multicategory shopper experience.

New simulation technologies offer the opportunity for more immersive and authentic VSS environments. Yet there has been little research on how authenticity of VSSs is impacted by newly available technology such as head-mounted displays, motion tracking, force feedback controllers, and application of place and plausibility cues. Thus, this dissertation asks whether immersive technologies have potential to provide highly authentic VSS environments. Of the many factors that may determine authenticity, this dissertation examines three; participants' sense of telepresence, the realism of shopper behaviour, and the effects of shopper locomotion alternatives.

An immersive VSS incorporating new virtual technologies was specifically designed and built for this research. Three studies were undertaken. The first compared perceived telepresence and usability between a desktop-operated VSS and an equivalent immersive walk-around VSS. The second examined the authenticity of shopper behaviour in the immersive walk-around VSS by comparing observed shopping patterns to those previously reported in the marketing literature. The third tested whether walk-around locomotion was necessary for authenticity, or whether a simpler teleportation method would result in equivalent shopper behaviour and emotions.

Results showed that immersive VSS systems are preferable to traditional desktop-operated systems with regards to telepresence and usability. Further, authentic behavioural patterns can be found in immersive walk-around store experiments, including plausibility of private label shares, pack inspection times, shelf-height effects and impulse purchases. Lastly, there were no differences in shopper emotions and purchase behaviour between walk-around locomotion and controller-based instant

teleportation, implying that the teleportation technique can be used, thereby reducing the required physical footprint for immersive VSS simulations. Collectively, the findings imply that marketers who study in-store shopper behavior can be confident using immersive VSS for their research as opposed to outdated desktop VSS technology.

Chapter 1: General Introduction

Understanding consumer behaviour is a crucial element for the ongoing success of every business. In order to compete in today's highly contested market environment, successful businesses are informed about consumers' needs and offer appropriate products and services that achieve consumer satisfaction. Accordingly, a whole sector of academic and commercial market research has been developed to help businesses understand consumer needs and guide their business strategy. For many decades, marketers resorted to rather subjective measures of consumer preferences when attempting to understand consumer behaviour. Tool sets typically include survey methods such as, face-to-face interviews, pen-and-paper surveys, telephone surveys, or online-surveys (Hulland, Baumgartner, & Smith, 2018). Such methods usually rely on subjective self-reports as a predictor of future behaviour. The reasoning behind such survey methodology is that human intentions will eventually lead to equavilant actions (see, for instance, Ajzen, 1991). Moreover, subjective self-reports have the advantage that they are comparatively cost-efficient and can be rapidly conducted, making them a widely used tool for market research up until today (Hulland et al., 2018).

Despite the wide adoption of attitudinal-based approaches to obtaining measures of behaviour, there is much debate around the accuracy of this type of data. A very prominent critique of subjective measures is the invalidity of the claim that intentions can predict behaviour. Sheeran (2002) amongst others argued that intentions do, in fact, not always lead to equivalent behaviour. The authors pointed out that the existence of an 'Intention-Behaviour-Gap' would significantly reduce the accuracy of predictions that were based on consumers' self-reports. Or in simple words, consumers do not always walk their talk. This is due to a neglect of contextual elements that alter decision-making at the point of purchase (Carrington, Neville, & Whitwell, 2010). Moreover, the research setting itself can pose a risk to the authenticity of consumer responses. A famous example for that is actively discussed in the literature and called the 'Social Desirability Bias' (Fisher & Katz, 2000). This concept describes the tendency of participants to tell researchers what they like to hear, in order to maintain a favourable image.

Due to concerns regarding methodological weaknesses arising from subjective surveys, researchers tried to find ways to collect consumer data with higher external validity. One approach is to design field experiments that allow observing shoppers when making purchase decisions in a contextually accurate setting, namely real-world store environments. Early findings suggest that methodologies which incorporate a realistic store environment arguably deliver the best results in terms of external validity (Burke, 1996). However, field experiments also come with the downside of being time consuming, causing extremely high costs, being dependent on retailer cooperation, and having the risk of a potential intervention by competitors (Breen, 2009; Burke, 1996; Klompmaker, 1976).

To address the limitations of field experiments the idea of digitally generated store simulations, or virtual simulated stores (VSSs), was born in the early 1990s. Since that time, VSSs have been successfully used for in-store shopper research and proven to be a market research tool with significant cost and procedural benefits compared to physical field experiments (Burke, 1996). More recently, a white paper published by the In-Store Marketing Institute shows that an increasing number of Fortune 500 companies in the United States recognised the potential of VSSs and started experimenting with virtual environments to enhance marketing practices and business operations (Breen, 2009). Some famous examples are companies such as Procter & Gamble, Intel Corp, Frito-Lay, Goodyear Tire & Rubber, and Kimberley-Clark. In 2013 virtual shopping simulations also tapped into the field of market research in New Zealand, with Colmar Brunton Research Ltd. developing a VSS that could deliver experimental in-store shopper research for their clients. This innovative technology quickly attracted the interest of two of New Zealand's largest FMCG companies, namely Fonterra and DB Breweries. Initial trials showed that this methodology could help companies improve their category management and growth (Fahy, 2013). After these early experiences, Fonterra started building their own research division focusing on the development of a VSS to inform their company's marketing and business strategies (Anthony, 2018). These events are an early indication of the relevance of this technology in contemporary marketing research practices and suggest that there is an increasing need for research in this area.

While VSS technology was embraced and quickly adopted by innovators in the FMCG and retail industry, knowledge about shopper behaviour in virtual simulated stores is still scarce and has not kept up with the rapid development of applications in this area. The limited research available shows that VSSs run on desktop VR computer setups resulted in purchase behaviour that closely resembled choices in corresponding physical conditions (Van Herpen, van den Broek, van Trijp, & Yu, 2016). However, these results came with some caveats. Some biases were observed mainly regarding shoppers' responses to promotions, their shopping time, purchase quantity, their brand switching behaviour, and the amount of private label purchases (Burke, Harlam, Kahn, & Lodish, 1992; Campo, Gijsbrechts, & Guerra, 1999). These biases could be a result of shortcomings with regards to shopper immersion leading to lower behavioural authenticity in simulated store environments. Advances in simulated store technology can potentially improve the immersiveness and believability of current systems. Especially the introduction of modern immersive Virtual Reality technology (also known as iVR technology) provides opportunities for virtual store research as it is known for its ability to create realistic and highly immersive virtual experiences (Mosadeghi, Reid, Martinez, Rosen, & Spiegel, 2016). Immersive VR systems use hardware such as head-mounted displays (HMDs) and motion tracking for in-store navigation, that provide not only more naturalistic interactions with the virtual store environment but also manage to effectively isolate the user's senses from sensory cues of the physical environment, enabling the shopper to solely focus on the simulated shopping experience. Thus, using this kind of technology could potentially lead to more authentic shopper in-store behaviour in VSS experiments. However, knowledge about how shopper behaviour is impacted by using immersive Virtual Reality store environments is still limited.

1.1 Definitions of Key Constructs in this Dissertation

Immersive Virtual Reality

In a broader sense, the term Virtual Reality (VR) is referred to as an electronic medium, similar to preceding technologies such as the telephone or television. Virtual Reality applications thereby use computer graphics for creating an artificial yet realistic copy of our actual world (Steuer, 1992). These 'virtual' worlds do not only provide visual or audible content like traditional media such as movies or television, but also allow real-time interaction between the user and the inherent virtual elements. In the early days of computer development, these interactions were rather rudimental. Users' perception of the virtual space was limited to visual cues delivered by a computer monitor and input undertaken by simple hardware such as mouse, trackball, joystick or keyboard. The degree of immersion in those early type of simulations was hence limited, as users still maintained a high level of awareness of their actual physical surroundings. Furthermore, the interaction with the virtual environment was far from familiar experiences with the real world. They had to use button-based input devices to trigger actions in the virtual environment, which was far more complicated than using their own hands. Moreover, this unfamiliar way of interacting with virtual objects constantly reminded the user that 'this is not real'. However, as technological development progressed more sophisticated hardware was developed that created much higher levels of immersion and a more naturalistic way to navigate and interact with the virtual environment. Computer hardware such as HMDs and haptic gloves were used to 'overlay' our actual senses and reinforce the belief of actually 'being' in the computer-generated space. Motion-tracking is used to allow the user to 'physically walk' through the virtual space giving even fewer doubts about the realism of interactions with the virtual elements. These new technologies, comprising of highly immersive digital input and output devices, are today referred to as ***immersive Virtual Reality (iVR) technology*** and see an increasing popularity around gamers, computer enthusiasts and representatives of industry and academia alike.

Virtual Simulated Stores

Virtual simulated stores (or VSSs) are computer graphic simulations of retail shopping environments which are a promising platform for experimental market research and online shopping. A *virtual* shopper can move through a 3D animated virtual store and purchase virtual products under the pretence that it was a real shopping trip. This allows the researcher to observe and analyse purchase decisions and behavioural patterns within the virtual store environment. This methodology can deliver much more detailed behavioural data than traditional methods such as questionnaires or interviews, which are criticised for the rather subjective nature of participant responses. VSSs are on the other hand much faster to conduct and more cost-efficient than actual in-store field-tests (Burke, 2018).

The first ever virtual simulated store system that found academic use was developed in the early 1990s and patented under the name *Visionary Shopper*. This store simulation software was developed by Prof Raymond Burke and allowed a shopper to select and pick products from virtual shelf facings. The simulation was displayed on a regular computer monitor while aisle navigation and shelf interaction was conducted via trackball and keyboard. However, over the years a number of more immersive hardware approaches were used, ranging from multi-monitor setups (Van Herpen, Pieters, & Zeelenberg, 2009), over CAVE (Cave Automatic Virtual Environment) systems (Meißner, Pfeiffer, Pfeiffer, & Oppewal, 2017), to immersive Virtual Reality setups that used head-mounted displays (Siegrist et al., 2019).

Despite more sophisticated systems being available, the research in this dissertation used immersive VR as a potential candidate for replacing desktop-operated systems due to the high degree of immersion that can be achieved for comparatively low cost. It further comes with a rich selection of available locomotion techniques for avatar movement. These range from realistic locomotion via physical walking (Schnack, Wright, & Holdershaw, 2019), in the following called 'walk-around', to more rudimentary controller-based techniques such as instant-teleportation (Bozgeyikli, Raij, Katkoori, & Dubey, 2016).

Telepresence

Telepresence is a concept that was first mentioned by Marvin Minsky (1980) and used to describe the perception of 'being' when an individual used a teleoperation system to remotely manipulate physical objects. This concept was later adopted for digitally generated virtual environments and referred to the degree a person feels present in them. It accordingly captures the idea of projecting oneself into a distant environment, whether that be physical (teleoperation and telecommunication) or figurative (Virtual Reality) (Draper, Kaber, & Usher, 1998). In some studies telepresence has been referred to using slightly different terminology including alternative terms such as presence (Sanchez-Vives & Slater, 2005), spatial presence (Wirth et al., 2007), or place illusion (Slater, 2009).

The most cited definition of telepresence found in the literature originates from Witmer and Singer (1998) who defined telepresence as: "The subjective experience of being in one place or environment, even when one is physically situated in another" (p. 225). Regarding Virtual Reality environments, telepresence describes the degree to which a user accepts the virtual environment as a real space and feels like 'being' in it. One could also say that the degree of telepresence is an indicator of the effectiveness of a Virtual Reality system to isolate a user from the physical world and give to them the illusion of being situated in the digital environment.

According to Steuer (1992) the level of experienced telepresence is determined by the virtual environment's vividness and the extent of interactivity with the environment. From a technical perspective, this can be achieved by delivering a visual experience using high quality graphics, the presence of context-related incidental sounds, and a natural user interface that requires motor actions that align with real-world experiences (Bracken & Skalski, 2009; Draper, Kaber, & Usher, 1999; Larsson, Vastfjall, & Kleiner, 2002). To achieve this, modern iVR systems utilise hardware components that seek to completely overlay the user's actual perceptive organs. These hardware components include VR headsets with integrated high-resolution computer displays, surround sound, instrumented data gloves, body suits, and a high-bandwidth, multi-degree-of-freedom force-feedback and cutaneous stimulation devices (Sheridan, 1996). However, most of this hardware is still in the experimental stage and has not found wide-spread application yet. Hence, today's consumer-grade hardware that is used in the VR entertainment industry is still limited to application of HMDs using handheld-controllers to deliver virtual environments through the senses of seeing, hearing, and a primitive form of feeling with the help of basic force-feedback technology.

But why is telepresence so important when using virtual environments, particularly in the field of virtual simulated stores? A number of studies have concluded that human's perception of their surrounding shopping environment have a crucial impact on their emotions and behaviour (Donovan, Rossiter, Marcoolyn, & Nesdale, 1994; Helmefalk & Hultén, 2017; Turley & Milliman, 2000). The purpose of a virtual simulated store is to replicate a real retail environment as closely as possible in order to arouse the same emotional and behavioural patterns that would occur in the real store. However, this requires shoppers to immersive themselves in the articficial store environment and actually feel present in it. Telepresence levels are an expression of the sense of 'being' inside a simulation and they increase the degree to which a shopper accepts the illusion of a store and behaves in an authentic manner. One could accordingly say that telepresence serves as a proxy for the expected authenticity of shopping behaviour in a virtual simulated store. This theoretical idea was supported by Waterlander, Jiang, Steenhuis, and Mhurchu's (2015) study. The research team conducted a desktop generated shopping experiment and measured participants' degree of telepresence. The researchers compared the behaviour in the virtual store with real world purchases that were tracked by collecting each participant's till receipts. Interestingly, participants with a higher degree of telepresence had a stronger overlap of actual and virtual purchases. This evidence hence suggests that marketers should strive for virtual store environments with the highest degree of telepresence possible in order to obtain authentic observations of shopper in-store behaviour.

And how is telepresence measured in practice? Most commonly telepresence is measured using subjective questionnaires and rating techniques (Nash, Edwards, Thompson, & Barfield, 2000) that are based on participants' self-reports during or after exposure to an artificial environment. For instance, questionnaires can directly assess the 'sense of being' on a scale from 1 to 7 and ask a participant to rate the amount of presence they felt in the virtual world. An example for this direct measurement is the Slater-Usoh-Steed (SUS) presence questionnaire (Slater, Usoh, & Steed, 1994). This questionnaire only contains six items and is a quick way to obtain a subjective evaluation of telepresence.

A second type of questionnaire is rather an assessment of the technical aspects of the simulation that influence telepresence, without asking the feeling of presence directly. These questionnaires are mostly much longer, however, have the advantage that they can help with evaluating the technical performance of a virtual reality system (Schnack et al., 2019). A widely used questionnaire that fits into this category is the Presence Questionnaire (PQ) developed by Witmer and Singer (1998). The PQ contains 32 questions each on a 1 to 7 scale and rates factors that are thought to be correlated with telepresence. As using the full PQ can easily lead to participant fatigue or is simply not feasible due to time constraints in a running experiment, some studies resorted to using only a selected number of items when using the PQ.

However, while subjective measures are generally accepted as a valid measure of telepresence there has been some criticism that was concerned about a range of limitations of this approach (Riley, Kaber, & Draper, 2004). For instance, participants sometimes have a poor ability to accurately recall and express VR experiences. Moreover, the used concepts and terminology might be confusing or too difficult for participants to understand. Lastly, there is a lack of standardisation as studies use different questionnaires which makes it impossible to compare the results. Due to these criticisms there have been some attempts to develop objective measures to assess perceived telepresence. Researchers recorded participants' behavioural reactions to a virtual environment, for instance to startling and unexpected events. These reactions were then compared to similar stimuli in the real world (Slater & Wilbur, 1997) and a stark overlap would indicate that participants would have a high sense of 'being' in the virtual environment. However, also this approach comes with drawbacks as it interferes with the task performance in the actual experiment and requires far more preparation and diligence than a simple questionnaire. Another observational technique is the use of physiological state changes in, for instance, posture, muscular tension, or cardiovascular function (Riley et al., 2004). The researcher can then compare whether physiological responses to a specific event in the virtual world correspond to a similar event in the real world. For instance, if a person's heart rate is increased when a tarantula is sitting on the table and scuttling towards the person, a good VR simulation that results in a high degree of telepresence would lead to a similar increase in heart rate. However, as these alternative methods still have not been researched to a large extent, strong evidence that specific physiological responses are correlated with telepresence is still missing (Prothero, Parker, Furness, & Wells, 1995; Szczurowski & Smith, 2017).

In the case of this dissertation, telepresence was assessed via subjective measures for three main reasons. Firstly, subjective measures are superior to other methods in terms of convenience and they lower the risk of participant fatigue. Secondly, triggering physical reactions (such as startling events) during a shopping experiment did not seem appropriate for the current experimental setting as it could have distorted shopper in-store behaviour and purchase decisions. Thirdly, resource constraints did not afford the author to acquire costly equipment for physiological measurements; furthermore, attaching more equipment to a participant's body during a shopping experiment would serve as a constant reminder of the experimental setting and reduce immersion and telepresence.

Embodied Cognition

The traditional view of motivation and actions is that the mind is the engine that powers the body and gives humans the trigger to act (Hung & Labroo, 2010). This basically means that solely our thoughts are what leads to action in any situation (Fishbein & Ajzen, 1975). However, more recent research showed that there is more behind human actions than this simple one-way relationship between thoughts and the body, which was traditionally reduced to a sole executional tool of our mind (D. Jones, 2017). The current view is that cognition is 'embodied' and that the body, in fact, has also a powerful influence on peoples' thoughts and emotions (Barsalou, 2008; Stepper & Strack, 1993). There are a number of studies that investigated different types of motor actions and their impact on human behaviour. For instance, it was found that nodding one's head amplified the level of agreement with a persuasive message (Wells & Petty, 1980). Hung and Labroo (2010) showed that firming one's calves augmented willpower and led to higher levels of self-control. Moreover, a study by Stepper and Strack (1993) explored the role of bodily states on emotions and found that an upright body posture lead to stronger feelings of pride compared to a slumped posture. Thus, the concept of embodied cognition seems to have relevant implications for shopping events, considering cognitive processes and emotions have a significant impact on consumer decision-making. This is especially true for shopping in virtual environments, where body movement and interactions with the environment are highly restricted, due to technical limitations of today's VR hardware, yet may be more flexible in immersive walkaround VSS.

1.2 Virtual Simulated Store Software used in this Dissertation

All experiments described in this dissertation were carried out using a simulated store software, which was developed by the author specifically for this research. Thus, the development and testing of the software formed the major focus of the initial stages of this doctoral project. The software with the name ViCoS (Virtual Convenience Store) was developed using the Unreal Engine 4 game development software. The Unreal Engine allows the creation of three-dimensional virtual environments and supports the most common input devices that enable interaction with virtual worlds such as mouse, keyboard, joystick, standard gaming-controller, hand-held motion-tracked controller, and hand-tracking. Moreover, applications developed with the Unreal Engine can be displayed on traditional computer monitors, mobile devices and Virtual Reality head-mounted displays (HMDs).

This flexibility of the development software allowed the creation of a desktop-operated as well as an immersive VR version of the same virtual store for the intended experimental comparisons. The chosen store format thereby was a replication of a New Zealand convenience store that was designed based on the local FourSquare brand. The store included virtual shelves and chiller units that were stocked with virtual replications of snack and beverage products that were available in the New Zealand market at the time of development. The stocked products were remodelled in an open-source 3D modeling software and textured with scans of the original physical product packages. Beyond visually designing the virtual replication of a convenience store, the Unreal Engine 4 software allowed programming back-end data recording that saved metrics of shopper-product interaction into an exportable CSV file. More detailed information about the developed virtual simulated store software will be provided in the method sections of chapter 3 and 4.

1.3 Main Contributions and Outline of the Dissertation

Problem Statement

The main purpose of this dissertation is to explore whether a VSS built using the new immersive VR technology can deliver an authentic shopping environment and provide new avenues for virtual simulated store research. The overarching research question hence is:

Do immersive technologies have potential to provide highly authentic VSS environments?

This problem will be approached by comparing the performance of different VSS technologies and further exploratory validation of the authenticity of observed shopper behaviour in an immersive walk-around VSS. The dissertation further expanded on this research question by investigating how VSS locomotion alternatives impact shopper emotions and behaviour in a simulated store environment. Thereby, the conducted research was carried out in three steps.

The first step involves comparing a traditionally used desktop-operated VSS system to an immersive walk-around VSS system with regards to achieved telepresence and usability. Based on current theory in telepresence, store simulations with higher perceived telepresence will lead to a stronger overlap of how shoppers behave in a simulated store and their actual real-life purchases (Waterlander et al., 2015). Thus, the system superior in telepresence should theoretically be the more effective system delivering more authentic shopper behaviour in virtual in-store experiments. The dissertation will evaluate which of the two compared systems should be preferred, if maximising the authenticity of shopper behaviour in virtual store experiments is desired.

The dissertation then presents an exploratory investigation of the authenticity of shopper behaviour in an immersive walk-around VSS environment. While several studies have validated shopper behaviour in desktop-operated VSSs (Burke et al., 1992; Campo et al., 1999; Van Herpen et al., 2016; Waterlander et al., 2015), little is known about shopper behaviour in immersive walk-around virtual store environments. The only existing study used a single shelf facing and did not allow shoppers to roam through a whole store and buy from multiple product categories (Siegrist et al., 2019). Therefore, this dissertation extends on these initial immersive VSS validation efforts and conducted an immersive walk-around VSS experiment that allowed shoppers to physically traverse an entire virtual convenience store and to conduct cross-category purchases. The subsequent analysis focused on behavioural patterns observed in the virtual store experiment and validated these against reports of behavioural patterns that are drawn from published sources.

The third step of the dissertation expands on the main research question and looks at the importance of avatar movement in immersive VSS environments. In shopper research, studies seem to rather arbitrarily select locomotion methods that are convenient for their experiment. However, research has shown that body movement and bodily states can impact an individual's emotions and decision-making (Barsalou, 2008), potentially leading to changes in shopping behaviour. Thus, there is a need to investigate the impact of a locomotion technique on shopper behaviour in immersive VSS environments to enable researchers to make informed decisions about the selected locomotion method in immersive VSS experiments. The dissertation hence investigates whether there are differences in shopper emotions and behaviour between two locomotion methods (controller-based instant teleportation and motion-tracked physical walking) within immersive VSSs. This will help determining whether controller-based techniques, that do not involve the act of physically moving through the virtual store, are equally efficient to more sophisticated walk-around techniques in virtual store environments.

In summary, the following problem statements were identified as not being answered by the existing literature:

1. Are immersive walk-around VSSs an improvement to already validated desktop-operated VSS systems with regards to telepresence and system usability?
2. Do shoppers demonstrate behavioural patterns in immersive walk-around VSSs that are congruent with how shoppers behave in real life?
3. Are immersive VSSs that use controller-based locomotion via instant-teleportation a viable alternative to more naturalistic systems that allow locomotion via physical walking (walk-around)?

These problem statements led to the development of following three key aims:

1. *To compare immersive walk-around VSS environments to desktop-operated VSSs with regards to users' perceived telepresence and system usability.*
2. *To investigate whether observed behavioural patterns in an immersive walk-around VSS shopping experiment are congruent with existing knowledge from the marketing literature.*
3. *To evaluate whether controller-based avatar locomotion, in absence of physical walking, impacts and thus potentially biases shopper emotions and behaviour.*

Contributions

The following section summarises the main contributions of this dissertation and highlights theoretical insights that have valuable managerial implications. The conducted studies firstly contribute to the ongoing validation of immersive VSS environment*s* and provide guidance for research and development of immersive VSS applications:

a. The research clarifies whether an upgrade from desktop-operated to immersive VSS systems has any benefits regarding the perceived level of telepresence and usability in a virtual store environment (chapter 2).

b. Results specifically allow recommendations regarding elements that contribute to stronger telepresence (chapter 2).

c. The work further provides valuable recommendations for conducting virtual store experiments and highlights key issues regarding technology use and experimental design (chapter 2).

d. The results will lastly indicate whether established purchasing patterns can be found in an immersive virtual simulated store environment and whether further research and development in this area is justified (chapter 3).

Secondly, the dissertation improves the understanding of bodily states and their impact on human emotions and decision-making. This is particularly important for avatar locomotion in immersive VSS experiments, as researchers have a choice from a huge variety of locomotion techniques with varying degrees of physical involvement:

a. The research demonstrates how the absence of physical walking impacts shopper emotions and purchase decisions (chapter 4).
b. By doing this it assesses whether controller-based locomotion is a viable alternative to more naturalistic locomotion via physical walking (chapter 4).
c. The work further provides insights into how emotional states of engagement, excitement and stress vary within a virtual shopping trip (chapter 4).
d. It lastly showcases how neuroscience instruments such as Electroencephalography (EEG) can be used for shopper research in immersive VR environments (chapter 4).

Outline of the Dissertation

The dissertation comprises of three research projects that address the main research question and formulated key aims. Research papers that derived from those research projects are presented in chapters 2, 3 and 4. Two papers have already undergone a peer-review process and were accepted for publication in academic journals. The third paper is currently in working paper stage and submission is planned for after completion of the PhD degree. In contrast to the original submissions, paper abstracts have been expanded to improve the logical coherence of the dissertation. The overall framework of the dissertation is shown in Figure 1.

The first research project, presented in chapter 2, investigates whether immersive VSS environments are superior to desktop-operated VSSs with regards to perceived telepresence and usability. The research project entails two experiments in a between-groups methodological design that involves a total of 111 participants who completed a simulated shopping trip. The findings will indicate whether an upgrade to immersive VSS systems is a feasible investment, given that perceived telepresence can lead to stronger authenticity of shopper behaviour. The research project has been published in the journal *Food Research International* with the title '*Immersive Virtual Reality technology in a three-dimensional Virtual Simulated Store: Investigating telepresence and usability*' in volume 117 in 2019.

Chapter 3 reports the second research project that is designed to explore and describe overall purchase behaviour in immersive walk-around virtual store environments. An exploratory shopping experiment in an immersive VSS environment was conducted with a total of 153 participants. Observed behavioural patterns are compared to equivalent data drawn from published sources in order to evaluate the overall authenticity of shopper behaviour in walk-around simulated store environments that use immersive VR technology. This study was published in the *Journal of Consumer Behaviour* with the title *'An exploratory investigation of shopper behaviour in an immersive virtual reality store'* and was included in volume 17, issue 2 in 2020.

After chapter 2 establishes the potential of immersive VSS environments regarding usability and shopper telepresence, and chapter 3 provides an assurance of the overall authenticity of observed shopper behaviour in an immersive walk-around VSS environment, chapter 4 delves into the design of immersive VSS applications, specifically into the aspect of store navigation methods. Accordingly, the next research project was focused on locomotion techniques for avatar movement in immersive VSS environments. The study compared controller-based locomotion via instant teleportation to a locomotion technique that used body-tracking to allow users to move through the virtual environment via physical walking. An immersive VSS experiment with a between-groups methodological design was conducted with a total of 71 participants. The findings highlight whether use of controller-based locomotion techniques, that are known for an absence of physical walking, lead to any changes in shopper emotions (as measured by electroencephalography) and behaviour compared to locomotion techniques that involve physical walking. The current stage of the research project is a working paper with the title '*Does the locomotion technique matter in immersive virtual store environments?*' and is aimed to be submitted to the journal *Journal of Retailing and Consumer Services.*

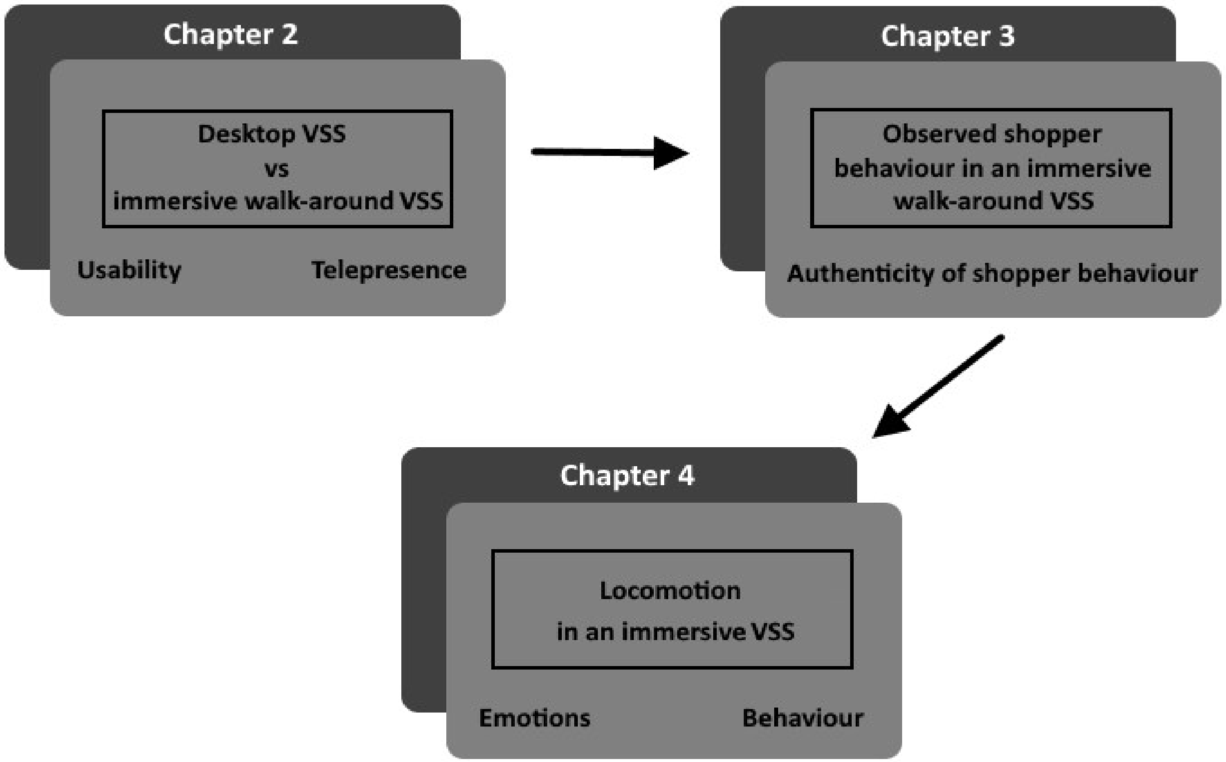

Figure 1: Framework of the dissertation

Chapter 2: Immersive virtual reality technology in a three-dimensional virtual simulated store: Investigating telepresence and usability

Extended abstract

The first research paper in this dissertation was produced to explore whether immersive walk-around Virtual Reality store simulations are an improvement over traditionally used desktop-operated store simulations. The specific research question was whether immersive walk-around VR store simulations have any benefits over their predecessors in terms of users' perceived telepresence and the perceived system usability. This was an important question to ask as, while desktop-operated systems have been validated on multiple occasions, to our best knowledge no study had looked at the authenticity of shopper behaviour in an immersive walk-around VR setting. While the research did not examine shopper behaviour itself, telepresence measures were used as a proxy for the expected authenticity of participants' in-store shopper behaviour. The original research article has been peer-reviewed and accepted by the journal *Food Research International* and was published in issue 117 in 2019.

In this study two experiments were carried out in a between-groups methodological design that involved a total of 111 participants who completed a simulated shopping trip. In the first experiment a conventional desktop computer setup was used to create the virtual simulated store using mouse and keyboard for navigation. The second experiment used immersive VR technology including a head-mounted display, body-tracking sensors, and hand-held motion-tracked controllers, which enabled navigation via body movement in a walk-around immersive VR environment. Participants purchased grocery items within each virtual simulated store environment, and post-hoc measures of perceived telepresence and usability ratings were compared.

Results showed that participants in the immersive VR group experienced stronger feelings of immersion and perceived naturalness of interactions with the store environment compared to the desktop group. Both factors potentially lead to enhanced perceived telepresence. However, the visual realism of virtual products and the grasping interface for immersive VR control of product inspection could be further enhanced by advances in immersive VR technology. This study has implications for marketing research as the use of immersive VR can potentially lead to more naturalistic shopping behaviour in virtual simulated stores. Based on the results in this chapter of the dissertation, further investigation of the authenticity of in-store shopper behaviour in immersive VR environments seems justified and will be followed up on in chapter 3.

2.1 Introduction

Research into the marketing of food products in grocery stores has progressed from consumer surveys to simulated retail stores (Silk & Urban, 1978) and then VSS[1] environments (Burke et al., 1992). However, following Burke et al.'s original publication in 1992, progress on the use of VSSs has been surprisingly slow (Breen, 2009). Findings about biased shopper behaviour in virtual store experiments (Burke et al., 1992; Campo et al., 1999) offer one explanation for market researchers' continued reliance on earlier developments in this field. These biases were potentially caused by insufficient telepresence experienced by shoppers in VSS environments that were used in previous research. Telepresence can be understood as the sense of 'being' in a virtual environment (Nowak & Biocca, 2003) and is shown to impact the degree to which shoppers behave realistically in a VSS (Waterlander et al., 2015). It is therefore expected to increase the accuracy of market share predictions of virtual store experiments. While there is knowledge about telepresence in conventional VSSs that are executed on regular desktop computers (Van Herpen et al., 2016; Waterlander et al., 2015) the extent to which the use of iVR[2] technology can improve telepresence has, to the authors' best knowledge, not yet been investigated in the extant literature. The present work fills this gap, and reports the results of a controlled comparison of telepresence and usability between a conventional desktop VSS and a fully immersive walk-around VSS. The paper sheds light on the potential of iVR technology to increase telepresence in VSS environments and provides suggestions for future research in this area.

Why Virtual Simulated Stores (VSSs)?

In food marketing research, marketers' decision-making usually relies on consumer preferences that are elicited using traditional market research tools, such as surveys and focus group interviews. However, a stream of research identifies an existing gap between purchase intentions and actual purchase behaviour (Carrington et al., 2010; Sheeran, 2002). Accordingly, criticism about the validity of consumer survey data led researchers to explore alternative methods of data collection. Methods that enable the collection of

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[1] **Virtual Simulated Store**

[2] **Immersive Virtual Reality**

actual purchase behaviour, such as test-market initiatives and physical simulated stores, are now well established. However, these methods require an enormous financial investment and the controllability is limited. In contrast, simulating a store environment in a virtual setting seems an obvious alternative, as virtual store simulations have lower costs for development and maintenance, they can be conducted more rapidly and they can be easily controlled for a multitude of environmental variables (Burke, 1996).

Validation of Conventional VSSs

Very little research in the past 30 years has explored the validity of this approach in predicting actual in-store behaviour. In a landmark study Burke et al. (1992), compared consumer choices in two simulated store settings (verbal product descriptions and a virtual store using images of shelf aisles) to actual purchases in a real grocery store. Results showed that while the virtual store was able to capture general brand preferences, consumers exhibited a range of systemic biases in shopper behaviour in terms of overall purchase quantity, reaction to price promotions, brand variety seeking and share of national brands. However, results of the virtual store experiment were overall closer to actual purchases than the verbal stimuli condition, suggesting that simulating an actual store environment produces more realistic behaviour than more rudimentary stimuli, which are commonly provided in 'pencil-and-paper' surveys. Burke et al. (1992) also concluded that although virtual simulated stores will not lead to entirely realistic behaviour, differences in relative behaviour that derive from manipulated independent variables can still be reliably detected.

S. Cohen and Gadd (1996) progressed the idea of simulating store environments and developed a virtual liquor store. Efforts made to validate the developed software found that choices in the VSS reflected participants' self-reported purchase patterns. Another attempt to validate VSSs was a study published by Campo et al. (1999), using a similar methodological design to Burke et al. (1992). Campo et al. concluded that data obtained from a virtual store environment corresponds closely to real life purchases, with the caveat of some systematic biases in respect to purchase quantity, share of generic brands, and time spent for the shopping trip. Similar results were reported by Desmet, Bordenave, and Traynor (2013) and Van Herpen et al. (2016) who compared consumer behaviour in a VSS to behaviour in a physical simulated store, as well as Waterlander et al. (2015) who used participants' actual weekly purchases as a benchmark.

Conventional VSSs in Consumer Behaviour Studies

Surprisingly, following the initial validation studies, only a few market researchers have utilised this kind of technology as a tool for academic studies focusing on consumer behaviour. The first consumer behaviour study that used a conventional VSS was published by Van Herpen, Pieters, and Zeelenberg (2005), who used a simulated supermarket environment for investigating scarcity effects in the wine category. Six years later Waterlander, Scarpa, Lentz, and Steenhuis (2011) showcased their 'Virtual Supermarket', a VSS that was used in several studies to investigate effects of taxes and subsidies (Waterlander, Steenhuis, de Boer, Schuit, & Seidell, 2012b), price discounts (Waterlander, Steenhuis, de Boer, Schuit, & Seidell, 2012a), discounts and health labels (Waterlander, Steenhuis, de Boer, Schuit, & Seidell, 2013), and sugar taxes (Waterlander, Mhurchu, & Steenhuis, 2014) on purchase decisions in a simulated store environment.

Systematic Biases and Telepresence

While previously discussed validation studies and pilot tests conclude that VSSs are sufficiently accurate (similarity between virtual and actual purchase behaviour) and as such, are approved for use in academic and commercial market research, a range of systematic biases (relating to purchase quantities, share of generic brands and duration of shopping trips) remain and require further investigation (Burke et al., 1992; Campo et al., 1999; Van Herpen et al., 2016). Thus, the question of how to further improve the validity of VSSs still needs to be addressed. A potential solution is to examine the concept of telepresence in the context of VSSs. Telepresence can be described as the subjective experience of being in one place or environment (for instance a virtual environment), while one is physically located in another (Witmer & Singer, 1998). Telepresence scores give an indication of to what extent a user feels immersed and present in a virtual environment. A high level of telepresence is assumed to lead to users' behaviour in a simulated environment more closely representing their actual behaviour (Slater, 2009). In this context, the results of Waterlander et al.'s (2015) test for telepresence in a VSS experiment found that participants who scored high in telepresence showed a stronger similarity between their virtual shopping behaviour and their actual weekly purchases. Thus, simulations that create stronger feelings of telepresence seem to be capable of leading to more realistic consumer behaviour in VSS experiments, and can potentially mitigate previously identified systematic biases in virtual shopper behaviour.

The Potential of iVR Technology for increasing Telepresence in VSSs

A potential way to increase perceived telepresence in VSSs is the use of iVR technology. Instead of relying on conventional navigation via mouse and keyboard, iVR equipment (such as HMD[3], body-tracking sensors, and motion-tracked controllers) makes interactions between user and virtual environment more intuitive and natural (Huang, Lucash, Simpson, Helgeson, & Klippel, 2019), and can potentially accelerate initial learning and familiarisation processes with simulated environments. Moreover, previous research demonstrated that iVR applications create stronger feelings of immersion and perceived telepresence in computer-generated virtual environments (Cummings & Bailenson, 2016; McGloin, Farrar, & Krcmar, 2011; Usoh et al., 1999). Thus, incorporating and validating iVR technology is the next stage in the development of VSSs for increasing telepresence, potentially leading to systems that can elicit more naturalistic shopper behaviour in virtual store experiments. The first publication to report about the use of iVR technology in the context of VSSs has been published by Verhulst, Normand, Lombard, and Moreau (2017). The researchers used an immersive VSS for investigating consumer perceptions and purchase behaviour in the fruit and vegetable category. The use of VSSs using iVR technology is yet to be validated.

The current study is the first to compare an immersive VSS to a conventional desktop system and clarifies (a) whether incorporating iVR technology can lead to higher levels of perceived telepresence and (b) whether the novel iVR equipment offers a degree of usability that is better or at least comparable with established desktop applications. It is hypothesised that participants using the iVR simulation will experience stronger feelings of immersion, perceive product representations as more realistic and will find it easier to navigate through and interact with the virtual store environment. The results have important implications for academic and commercial market researchers as they clarify whether investing in iVR technology can potentially improve the quality of data gained by VSS experiments.

[3] **Head-mounted Display**

2.2 Material and Methods

Two virtual shopping experiments were conducted in order to collect telepresence and usability ratings. The experimental logic was based on Nichols, Haldane, and Wilson (2000) who compared users' telepresence scores in a simulation using different display technologies. The first experiment collected data from a VSS executed on a conventional desktop setup using LCD-Screen, mouse and keyboard. The second experiment used a VSS that utilised iVR Technology including an HMD, hand-held motion-tracked controllers and body-tracking technology (see Appendix A). Both setups were executed on the same workstation equipped with a 6^{th} generation Intel quad-core processor (i7-6700k), 32 GB DDR4 RAM, and a dedicated Graphic Processing Unit (NVIDIA GTX 1080 chip).

Experimental conditions

In the first stage of the data collection participants used the conventional desktop VSS (Figure 2). Products were picked up by double-clicking on a product with the left mouse button, which moved the product in front of the user's view until the mouse button is depressed. This view mode allowed product inspection by moving the mouse to rotate and view the product from different angles. The product can be placed into the shopping cart by clicking the right mouse button or be returned to the shelf by releasing the left

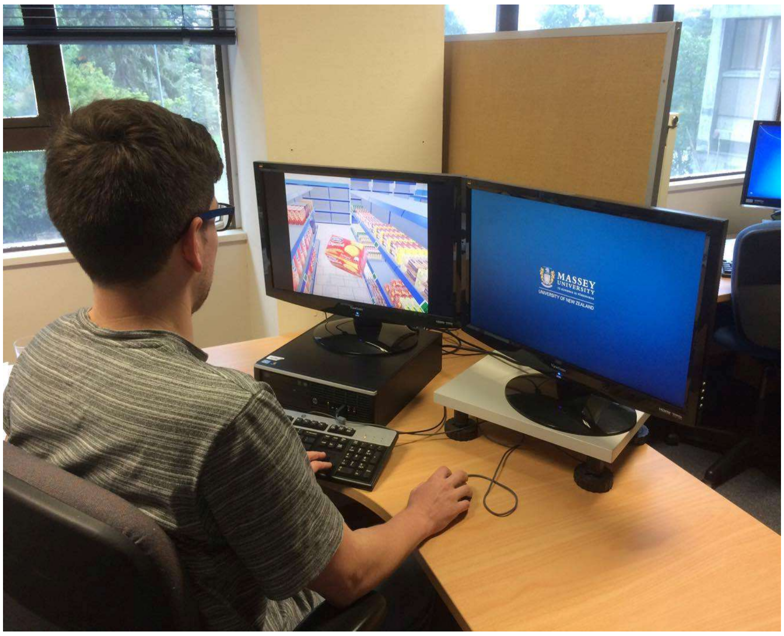

Figure 2: Desktop-operated store simulation

mouse button. To finish the shopping procedure the user moves in front of the check-out counter and a button appears on the screen to click and end the shopping process. In this version of the VSS only the fridges emitted noises, and the sales clerk mostly stood in the same position with some slight movement of the head and arms only. Fridges were displayed as open, therefore participants were not required to open any fridge doors to access products.

In contrast, the second group used the immersive VSS (Figure 3) that employed a stereoscopic HMD[4] and hand-held motion-tracked controllers provided by HTC Corp. (Taoyuan, Taiwan). Participants' movement was tracked by two base stations that covered an area of 4 by 4 meters. Participants navigated through the VSS by walking in a confined physical space. The controllers enabled participants to collect a shopping basket and interact with products. Products could be picked up and in addition be rotated and enlarged by using the controller's touchpad. This enabled participants to closely inspect the package labelling. Selected products were simply placed into the shopping basket. To finish the shopping, participants had to place the shopping basket in a marked area on the check-out counter. In contrast to the conventional desktop simulation, this

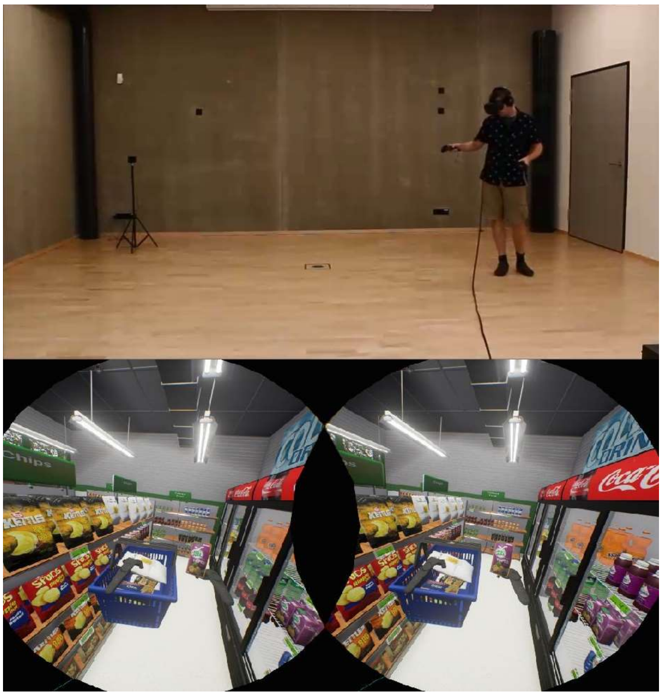

Figure 3: Participant during the iVR experiment

[4] **HTC Vive with Lighthouse Tracking Technology**

VSS included a multitude of environmental sounds. Participants could hear the noise of fridge compressors, sliding fridge doors, passing pedestrians and cars outside the store, product placement into the shopping basket, as well as the sales clerk typing on the cash register and talking to the participant. In addition, the sales clerk interacted with the environment as he sporadically moved around, counted products on a shelf and used the cash register. Based on the differences in display technology, naturalness of the control devices, and the design of the virtual store environment compared to the desktop environment, it is expected that the iVR store simulation will create a more immersive shopping experience which translates to stronger perceived telepresence, while offering at least an equivalent degree of usability.

Participants

The convenience sample for this study consisted of 111 students and staff members recruited from a New Zealand university. Recruitment was conducted via advertisements in social media groups for students and via word-of-mouth. Most participants were in the age range of 20-29 years (45.9%) and the gender distribution was male (38.3%) and female (61.7%). The majority of participants had not played computer games in the past six months prior to data collection (62.2%), whereas nearly all participants were familiar with using mouse and keyboard due to being regular computer users (99.1%). This knowledge was important for the study as it was assumed that previous exposure to computer technology may impact on participants' ability to familiarise with and utilise the control interface of the tested simulations (Gozli, Bavelier, & Pratt, 2014). Due to recruitment at the university campus environment the majority of participants (84.7%) had a Bachelor or higher degree (see Appendix B).

Experimental Procedure

The virtual store experiments in this study followed the procedures outlined by Desmet et al. (2013). Before engaging in the virtual shopping task participants in the desktop group received written instructions with detailed information about how to navigate inside the VSS environment and how to pick up and purchase products. The iVR group was additionally instructed verbally and received a brief demonstration of how to operate the equipment. This was seen as necessary as the iVR controllers were too complex to intuitively understand. Comparable with a real shopping experience, all participants were instructed to explore their allocated VSS at their own pace and to inspect and purchase any number of items they wanted. No time restrictions were imposed on the shopping experience. Participants were further explicitly asked to use all functions of the software, especially the view modes that allowed rotating the products for inspecting the product labelling. After the virtual shopping experiment, participants answered a range of questions about their perceived telepresence in the VSS environment and the usability of the software. As the study was solely focused on telepresence and usability, participants' purchases were not recorded. Further, open-ended questions were included to obtain participants' thoughts and feedback on their participation in the study and demographic data were collected.

With regards to participant health and safety, it was decided to take some extra precautions in the iVR group to guarantee participants' wellbeing throughout the experiment. Previous research reports that using HMDs can potentially lead to simulator induced motion-sickness (Keshavarz & Hecht, 2011). This is explained by the sensory conflict theory (Reason & Brand, 1975) that links symptoms to a disconnection between visual and vestibular senses. These symptoms mostly occur when iVR applications use unnatural navigation techniques such as hand-held input devices (Nichols & Patel, 2002). Navigation via body-tracking technology as used in this study, in contrast, not only leads to higher levels of telepresence (Usoh et al., 1999) but also aligns participants' head and body movement with changes in visual cues and is hence assumed to avoid experiences of motion-sickness (Templeman, Denbrook, & Sibert, 1999). Nevertheless, participants were advised to immediately discontinue the experiment should they become unwell. As a precaution they were asked to sit for a couple of minutes after concluding the experiment to readjustment to the physical environment. Except for one participant, who experienced minor dizziness during the first seconds of the virtual shopping trip, no other cases of motion-sickness were reported during the data collection.

Measurements

Telepresence

To measure telepresence six items were adapted from Witmer and Singer's (1998) 'Presence' Questionnaire (PQ). The original PQ contains 32 items (see Witmer and Singer, 1998, p. 232-233) to measure four factors: Control Factor (*CF*), Sensory Factor (*SF*), Distraction Factor (*DF*), and Realism Factor (*RF*). These factors contribute to feelings of telepresence and hence allow an assessment of how 'present' a user feels in a virtual environment. One advantage of Witmer and Singer's PQ is that it does not attempt to measure reported feelings of presence directly, as for instance in the presence questionnaire developed by Slater et al. (1994), but instead measures aspects of the simulation that are known to affect perceived telepresence. By using the PQ, it was not only possible to measure telepresence, but also to assess how well each developed simulation performed in terms of those proposed aspects. For this study original PQ items were slightly modified in order to use the same 7-point Likert scale across the whole questionnaire. For instance, the original item "How closely were you able to examine objects?" that could be rated on a scale from 1 ('Not closely') to 7 ('Very closely') was transformed to the item "I was able to closely examine objects" with the answer ranging from 1 ('Entirely Disagree') to 7 ('Entirely Agree'). In order to avoid potential respondent fatigue associated with the time frame required for completing all survey stages, the presence questionnaire was reduced to six items that relate to the graphics, controls, audio and general naturalism. Hence the results serve as a proxy measure that can indicate a tendency of the used technology to achieve higher telepresence scores. Previous research further pointed out that using stereoscopic displays enhance the visual realism in virtual environments (Lo & Chalmers, 2003), which is assumed to increase perceived telepresence (Berneburg & Herder, 2008). It was hence decided to include an additional item to assess the level of perceived visual realism of the virtual products. The item was based on a questionnaire used by Baños et al. (2000) and was again converted to a 7-point Likert scale.

Usability and Open-ended Questions

The second part of the questionnaire tested for overall usability by applying selected scale items adopted from Waterlander et al. (2011). The items included questions that asked for the overall ease of understanding of the software, the ability to easily navigate the VSS and the ability to find all products. The third and final part of the questionnaire contained a number of open-ended questions that were designed specifically for this study. Participants were asked to express their initial thoughts, report aspects of the simulation that frustrated them, and offer final comments and improvements.

Data Analysis

Scores for telepresence, usability and visual realism for each group were first analysed for normality of the sample distribution and homoscedasticity of variances as suggested by Granato, de Araújo Calado, and Jarvis (2014). Normality was tested using a Shapiro-Wilk test, as recent research found this method to be superior to other commonly used methods (Razali & Wah, 2011). For testing homoscedasticity a Levene's test for homogeneity of variances (Levene, 1960) was performed. Results of the preliminary analysis indicated that neither groups' scores were normally distributed. However, variances were found to be equal amongst groups. Due to the non-standard distributed character of the sample, a Wilcoxon W non-parametric test was used to compare means between both experimental groups (Desktop vs. iVR). Effect sizes were indicated by using calculated z-scores.

Interrelations between item scores and participants' demographic profiles were also examined using a correlation matrix. Detected differences were further investigated for effect size using contingency tables. Significance was determined using Wilcoxon W or Kruskal-Wallis test statistics ($p<.05$).

Qualitative analysis of the open-ended questions was performed using thematic analysis as described by Braun and Clarke (2006), and enabled identification of similar themes between participants' answers. Commonalities between participants' answers were analysed in order to identify themes that were connected to the research question.

2.3 Results

Telepresence

Between groups comparison

First, the study investigated whether a change from traditional desktop setups to iVR technology can potentially lead to higher perceived telepresence in the VSS (Figure 4). Results of the mean scores for the proxy measures of telepresence are presented in Table 1.

In the current setup iVR technology led to major improvements in respect to naturalness of interactions with the environment ($z=-2.281$, $p=.023$), as well as the effectiveness of visual aspects ($z=-3.696$, $p=.000$), and the emitted ambient noise ($z=-4.749$, $p=.000$) to support participants' perceived immersion into the VSS environment. The results also suggest that the iVR technology slightly improved participants' ability to closely examine objects ($z=-.484$, $p=.631$). The lower score obtained for 'control interface interference' indicates another improvement with the iVR control interface as

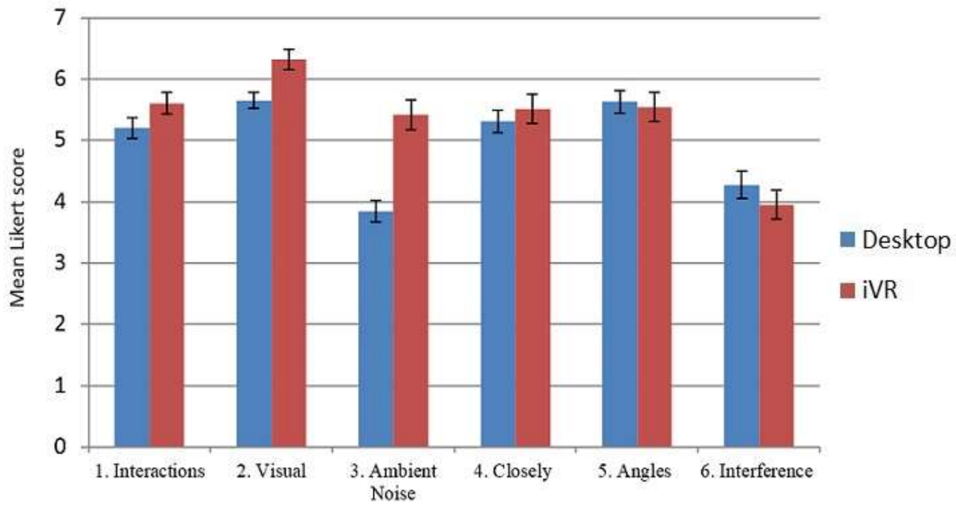

Figure 4: Mean Likert scores of telepresence ratings

this finding suggests that it interfered less with the performance of the assigned task (z=-.901, p=.746) compared to the desktop setup. In contrast, the results indicated that the desktop system performed slightly better in enabling participants to examine objects from different angles (z=-.823, p=.412). Overall, the iVR system performed better in five of the six measured items, with the caveat that group differences for two of the five better performing items (i.e. 'lower control interface interference' and 'improved ability to closely examine objects') were not statistically significant for the sample size employed in this study.

Effects of participant's age on telepresence (iVR group only)

For the iVR group a significant correlation was identified between participants' age and the interference of the control interface (Kendall: τ=.361, p=.001). The Kruskal-Wallis analysis confirmed that the mean score for the 20-29 age group was significantly lower than for each of the other groups. An η^2 value of .244 (p=.005) suggests that 24.4% of variability in rank scores between groups is attributed to age. This value indicates a medium to large effect size (J. Cohen, 1988). Further, pairwise comparisons found that the strongest effect could be observed between the age groups 20-29 and 40-49 (η^2= .196, p=.003), with the second strongest effect found between the groups 20-29 and 50-59 (η^2=.141, p=.012). The smallest observed effect size was found between the age groups 20-29 and 30-39 (η^2=.138, p=.004). Thus, the results suggest that participants belonging to the 20-29 age group found the control interface less interfering and hence easier to use than participants in the upper age categories. This effect was not found for the desktop group.

Table 1: Results of between groups comparison

	iVR (n=62)	Desktop (n=49)	Z-Score
	Mean-Likert		
Telepresence (Witmer & Singer, 1998)			
The interactions with the environment seemed natural *(CF)*	5.61	5.20	-2.281*
The visual aspects helped me feel involved *(SF)*	6.32	5.65	-3.696*
The ambient noise helped me feel immersed in the virtual environment *(SF)*	5.42	3.85	-4.749*
I was able to closely examine objects *(SF)*	**5.52**	**5.31**	**-.484**
I could examine objects from different angles very well *(SF)*	**5.55**	**5.63**	**-.823**
The control interface interfered with the performance of assigned tasks or with other activities *(DF, CF)*	**3.95**	**4.27**	**-.901**
Usability (Waterlander et al., 2011)			
The program was easy to understand	**6.10**	**5.90**	**-1.774**
I could easily find my way around the virtual convenience store	6.34	5.69	-3.523*
I could relatively easily find all products in the virtual convenience store	**5.90**	**5.67**	**-1.236**
Visual Realism of Products (Baños et al., 2000)			
The products appeared to be realistic to me	**6.10**	**6.18**	**-.323**

*** Significant difference in means between both groups (p < 0.05 Wilcoxon W).**

**** (CF) = Control Factor; (SF) = Sensory Factor; (DF) = Distraction Factor (Witmer and Singer, 1998)**

Visual realism of products

Between groups comparison

This part of the questionnaire tried to assess whether the stereoscopic nature of the HMD could display virtual products as more realistic than displayed by the desktop setup. In absolute numbers, results suggest that participants in the desktop group perceived the products as slightly more realistic compared to the iVR group (z=-.324, p=.746). However, there was no significant difference between the groups.

Effects of previous gaming experience on visual realism of products (desktop only)

Further findings suggest that participants' previous computer gaming experience had a significant impact on the visual realism of the products in the conventional desktop VSS (Kendall: τ=.297, p= .011). The effect size was investigated using a 2x2 contingency table and calculated z-scores, showing that participants with previous gaming experience had a significantly lower mean score in visual realism (z:-3.131, p=.002 Wilcoxon W). This finding indicates that participants who had not played computer games in the past six months considered the products as more realistic than those who had played computer games. However, this effect was not observed for the iVR group.

Usability

Between groups comparison

The second part of the questionnaire explored the iVR technology's capability to improve the ease of use of the VSS application (see Figure 5). In this context the iVR group had overall higher mean scores in all three items. In fact, they reported stronger agreement that they could easily find their way around the virtual store (z=-3.523, p=.000) compared with responses from the desktop group. The iVR group's level of agreement that they could easily find all products was also comparatively higher than for the desktop group (z=-1.236, p=.218). Moreover, the iVR software was rated as easier to understand (z=-1.774, p=0.76). Accordingly, overall the results indicate that the iVR system was

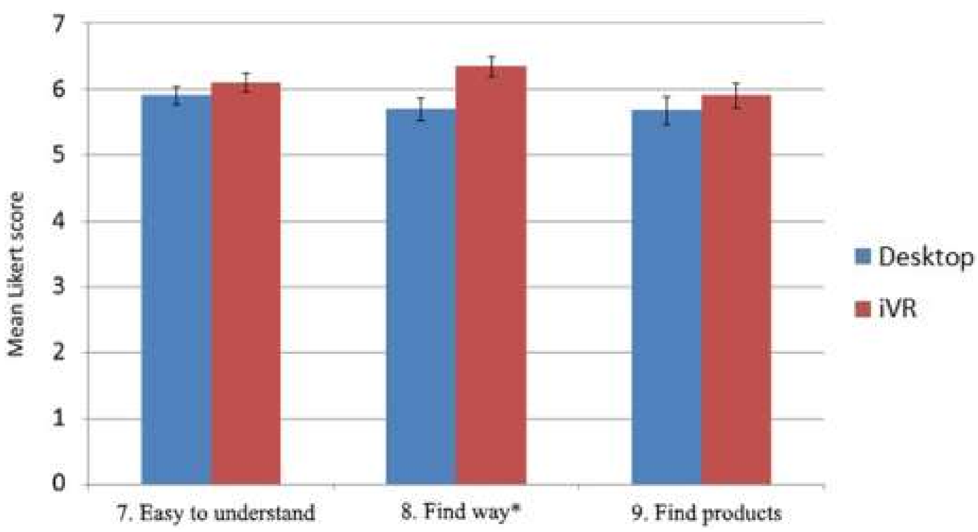

Figure 5: Mean Likert scores for usability ratings

perceived as more user-friendly than the desktop system, although not all effects were significant.

Responses to open-ended questions (iVR group)

The qualitative analysis of responses from the iVR group revealed several themes relating to the overall research aim that was to understand differences in telepresence and usability between the tested VSS systems (see Table 2). The most dominant themes to emerge from the open-ended questions were that *higher resolution of product labels would be desirable* and *the product rotation needs improvement*. In terms of the resolution, a number of people reported that blurriness occurred when they tried to magnify product labels. Participants attributed this blurriness to an insufficient resolution of the product scans and suggested that it be increased. Regarding the rotation of products, ten participants suggested that the way the remote controls operated was too complicated and not intuitive. Two participants pointed out that the problems were caused by the way the products were rotated. One illustrative statement was "To inspect labels I had to very awkwardly contort my wrists, even despite the rotate function".

Table 2: Identified themes in thematic analysis (iVR)

Negative	*f**
Higher resolution of product labels would be desirable	**10**
The rotation of products needs improvement	**10**
The room should be bigger (avoid obstacles)	**5**
The cable of the HMD felt disturbing	**4**
VR Gloves instead of controllers would be better	**4**
Glasses did not fit under HMD	**1**
Hair did not fit under HMD	**1**
Control setting not wheelchair friendly	**1**
Positive	
Behaviour was like in a real store	**4**

f= Number of respondents

Another relevant theme identified by participants was that *the cable that connects the HMD to the computer felt distracting*. Their comments included that the simulation "Would be much improved if there were not any wires following you around", and that "…an integrated wireless helmet rather than two piece wired array" should be used.

Another theme referred to *the choice of input devices* and, in particular that VR Gloves are superior to hand-held controllers. Four participants did not consider the hand-held controllers as sufficiently natural and intuitive and suggested the use of alternative input devices such as VR gloves or hand-tracking. Their statements included "Use virtual hands. The controllers are klutzy…" and "If a glove could be used instead of the controller, I think this could improve the experience and make it more natural".

In terms of in-store behaviour some participants reported that shopping patterns in the immersive VSS tended to resemble their actual behaviour, leading to the theme *behaviour was like in a real store*. In total four participants indicated that they felt like they were in a real store or they were in a real shopping situation. For instance, one participant reported "I felt automatically drawn to objects I would normally buy, but the environment lent itself well to examining objects I had not considered before". Accordingly, the immersive VSS seemed to be successful in simulating a context of competing product stimuli that single product dummies or product pictures could not achieve. For example, one participant stated that "…I was able to…pick the product that I was not very familiar with and read the label which eventually influenced my decision", which suggests that the ability to pick up and inspect products influenced participants' decision making. Similarly, another commented "It feels like I was about to do my grocery shopping like I would do in my neighbourhood". Thus, participants' self-reports suggest that the simulation seemed to successfully elicit realistic shopper behaviour.

The last three themes revealed issues with the fitting and use of the iVR equipment. For example, one participant commented that the HMD did not accommodate people with thicker or voluminous hair, while another participant indicated that it was not comfortable for people wearing big spectacles. Further, one participant pointed out barriers for people who require a wheelchair. The simulation required participants to permanently press down a controller button to hold and carry the shopping basket. For the user to move his wheelchair he had to use both hands which prevented him from operating the controllers at the same time and hence from finishing the shopping task.

2.4 Discussion

With regards to telepresence, findings indicate that iVR technology has the potential to outperform conventional desktop applications. Participants in the iVR group not only found interactions with the environment using motion-tracked controllers more natural, they also felt more immersed by (a) visual aspects using a stereoscopic HMD and (b) the presence of more audio cues. Assuming that higher item scores lead to stronger feelings of telepresence (Witmer & Singer, 1998), these findings are in line with previous research that investigated influences of control devices, display type and audio cues on telepresence (Hendrix & Barfield, 1996; McGloin et al., 2011; Nichols et al., 2000; Seibert & Shafer, 2017). Furthermore, some participants reported that their in-store behaviour resembled their real-life purchase decisions to a large extent. This finding reinforced the assumption that high telepresence leads to more realistic behaviour as argued by Slater (2009).

In addition, the iVR group reported fewer interferences of the control interface with the performance of tasks. Although the difference between groups was not significant, the findings nevertheless indicate that the hand-held motion-tracked controllers were generally perceived as easier to use than the mouse and keyboard setup.

In terms of the ability to closely examine objects, although the iVR system obtained a higher mean score, the observed difference between both groups was not significant. This outcome was unexpected as the iVR system offered an additional 4x zoom and a more naturalistic way to handle virtual products, which should have made reading package printing much easier. However, the finding that the iVR system did not perform significantly better can potentially be explained by the fact that participants did not try to read the package labelling and made purchase decisions solely on familiar brand cues or price, rather than checking for detailed functional product information on pack (Park & Lessig, 1981). Hence, the additional functions the iVR system offered over the desktop setup might not have played a role in that particular situation.

Further, in terms of the ability to examine objects from all angles, it was expected that the iVR system would clearly outperform the conventional desktop system. This was due to the iVR system offering higher controllability and a more naturalistic handling of virtual products. However, participants did not perceive this system as superior to a conventional mouse and keyboard setup, which can potentially be explained by responses to the open-ended questions. Notably, 19 participants reported problems with the iVR system's control design. Specifically, the way to rotate the products with the touchpad was perceived as too complicated. Four people recommended using technology such as hand-tracking or the use of VR gloves to further enhance the naturalism and usability of the controls. While such technology was initially considered for this study, issues of availability prevented incorporating this kind of equipment into the current research design.

As expected, offering a wider range of in-store sounds in the iVR simulation led to significantly better results in mean scores for the item ambient noise. Consequently, results indicate that a richer audible environment positively affected participants' perceived level of immersion in the virtual store environment. This finding is in line with existing literature that highlighted the importance of sonification for perceptual realism leading to stronger immersion in media such as movies (Anderson, 1998) and video games (Grimshaw, 2008).

The item for visual realism of products found no significant difference between the means in both groups. This finding was unexpected as previous research found that stereoscopic HMDs create a high degree of visual depth that leads to more realistic visual content (IJsselsteijn, de Ridder, Freeman, Avons, & Bouwhuis, 2001; Lee & Kim, 2008; Lo & Chalmers, 2003; Rooney & Hennessy, 2013). However, some insights from the open-ended questions can potentially explain this contradictory result. Some participants reported about shimmery/grainy graphics and blurriness when magnifying product labels. This negative visual experience might have interfered with the visual realism of products. Participants recommended using a higher resolution for the product scans. These suggestions are in line with Lee and Kim (2008) who further found that increasing the resolution of video images led to an enhanced visual realism.

Looking at usability, in general participants found it significantly easier to navigate the VSS using the iVR equipment. Moreover, there was a minor improvement in their ability to locate the products in the virtual store. These findings suggest that navigating via body-tracking and head-tracked HMD had a positive impact on their product searching ability. This finding is partly in line with Pausch, Shackelford, and Proffitt (1993), who concluded that HMDs using head-tracking performed better in generic search tasks than stationary displays with a hand-held tracking device. The observed lack of significance in the case of product search capability could be explained by the relatively small dimension of the virtual store, covering only a floor space of 16 square meters, which made it very easy in general to locate products. Repeating the same experiment in a larger store format might lead to participants utilising the full potential of the HMDs search capabilities and a significant advance compared to a desktop system.

Further findings showed that some participants' individual characteristics had a significant impact on the performance with the software. For instance, older participants tended to struggle more with the iVR controllers than younger participants did. As food market researchers want to reach out to a diverse population, future developers of control interfaces are advised to take into account older users and design an interface that focuses on simplicity and intuitiveness (IJsselsteijn, Nap, de Kort, & Poels, 2007). Moreover, previous video gaming seemed to have had an influence on the visual realism of products in the desktop group. It is assumed that people who are familiar with modern video gaming have a higher expectation of realistic high-resolution graphics than those who are inexperienced, as the experienced are more aware of the state-of-the-art in the current video gaming industry.

The open-ended questions further pointed out a number of improvements for future software development. First, participants reported that they felt distracted by the cable connecting the HMD to the computer, which had a disruptive effect on the virtual shopping experience. Researchers using iVR technology for future VSS experiments are hence advised to adopt wireless solutions for HMDs. Furthermore, the iVR simulation did not cater for the specific needs of some participants, partly due to the equipment and partly due to the software. Thus, it is recommended to investigate whether participants who use oversized spectacles could instead use contact lenses for the experiment, whether alternative strapping systems for HMDs can be developed for those with voluminous hair, and whether a control design can be developed to suit wheelchair users. Future research should extend the findings and enhance the understanding of iVR technology's impact on factors that determine perceived telepresence by employing the full presence questionnaire developed by Witmer and Singer (1998). Alternatively, other methods that directly measure perceived telepresence can be examined, such as the Slater-Usoh-Steed Questionnaire (Usoh, Catena, Arman, & Slater, 2000) or objective measures such as physiological reactions (Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 2000; Meehan, Razzaque, Insko, Whitton, & Brooks, 2005) and social responses (Sheridan, 1996). As the validity of self-reported telepresence measures is still under debate (Schubert, 2009; Slater & Garau, 2007), biometric or social observations can potentially provide a more reliable approach for future studies. More importantly, the direct impact of iVR technology on observed shopper behaviour needs to be the focus of future research in order to assess whether systematic biases in shopper behaviour can successfully be reduced by more immersive VSS systems.

Once further developed and tested, VSSs using iVR technology offer an attractive alternative to traditional survey techniques due to the potential to capture actual in-store behaviour rather than stated intentions. This is complemented by the uniqueness of creating a holistic food retail environment that enables food marketers to control for environmental factors which traditional methods could not do before. Utilising these new features will open a wide field of applications with new opportunities for testing various effects of marketing interventions such as food packaging design (Rebollar et al., 2017), food-advertising (Vukmirovic, 2015) or retail store layout (Baker, Levy, & Grewal, 1992) on consumers' in-store behaviour. Because of this immense potential, academic and commercial food market researchers should not forego the emerging opportunity offered by iVR technology to advance research in virtual consumer in-store behaviour.

2.5 Conclusion

The present study contributes to the understanding of iVR technology in the context of VSS environments used for consumer behaviour research. It investigated whether applying iVR technology in a VSS has the potential to increase perceived telepresence and offers an equivalent level of usability compared to traditional desktop systems. This research question was addressed by comparing participants' post-experimental telepresence and usability Likert-scores between two experimental groups (Desktop vs. iVR). Moreover, a set of open-ended questions was designed to explore the reasons for previous telepresence and usability ratings and suggests improvements for future development of VSS applications.

Results conclude that VSS environments using iVR technology show a tendency to increase perceived telepresence. In particular, the presentation of visual cues and the interactivity with the virtual environment led to participants' feeling more immersed. Further, the usability of novel iVR equipment has been found to be on a par with the traditional mouse and keyboard setup. This implies that incorporating iVR technology into existing conventional VSSs can potentially lead to more naturalistic shopper behaviour in virtual experiments, without jeopardising the user-friendliness of the simulation. The ability to elicit more naturalistic shopper behaviour could significantly decrease systematic biases in virtual shopper behaviour and lead to more accurate depictions of actual in-store behaviour. This implication was confirmed by participants who reported having shopped as they would in a real store. While iVR has some shortcomings in terms of visual realism of products and controllability relating to ease of product handling, these flaws can be addressed by future software improvements. Overall, VSS environments using iVR technology offer bright prospects to enhance modern food market research and marketers are encouraged to delve into this promising field and to explore emerging opportunities.

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STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Alexander
Name/title of Primary Supervisor:	Schnack
Name of Research Output and full reference:	
Immersive virtual reality technology in a three-dimensional virtual simulated store: Investigating telepresence and usability	
In which Chapter is the Manuscript /Published work:	Chapter 2
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	65
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Literature review, building virtual environment, planning experimental design, data collection and analysis, writing manuscript first draft, preparing manuscript artwork, contributing to manuscript revisions and correspondence with reviewers.	
For manuscripts intended for publication please indicate target journal:	
Food Research International	
Candidate's Signature:	Alexander Schnack Digitally signed by Alexander Schnack Date: 2020.01.16 13:52:05 +13'00'
Date:	16/01/2020
Primary Supervisor's Signature:	Malcolm John Wright Digitally signed by Malcolm John Wright Date: 2020.02.17 12:27:10 +13'00'
Date:	17/02/2020

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Chapter 3: An exploratory investigation of shopper behaviour in an immersive virtual reality store

Extended abstract

The first study presented in chapter 2 confirmed that immersive walk-around VR simulations are superior to traditionally used desktop-operated simulations with regards to users' telepresence levels and system usability. However, while telepresence scores provide a first indication of the authenticity of shopper behaviour, alone they do not provide sufficient validation of behavioural patterns in virtual stores, such as comparisons against real-life purchases. This limitation is addressed by the research paper that is presented in the following chapter 3.

The presented paper's key aim is to validate behavioural patterns in an immersive Virtual Reality store by investigating whether observed behavioural patterns are congruent with existing knowledge from the marketing literature. This exploratory approach will help with assessing whether plausible purchase patterns occur in an immersive virtual shopping task. The current research seems necessary, as there is yet little knowledge published on the authenticity of shopper behaviour in immersive walk-around virtual store environments. The original research paper has been published in the Journal of Consumer Behaviour in volume 19, issue 2, 2020.

In essence, the presented study reports results from 153 multicategory shopping trips conducted in an immersive virtual convenience store. Observed shopper metrics and theoretical effects are compared with equivalent data obtained from published sources and found to be consistent across all measures. Specifically, shoppers purchase a plausible share of private label brands, more private label brands in lower consumption pleasure product categories, more products from higher compared to lower shelf positions, make a plausible proportion of impulsive purchases and spend less time inspecting familiar versus unfamiliar brands. Further, time in-store, total spending and product handling time are higher for women than for men. These exploratory findings show that participants continue to exhibit realistic shopper behaviours in an immersive virtual simulated store. Such stores are therefore a cost-effective alternative to other methods for measuring consumer behaviour. They offer significant potential for innovative experimental designs in consumer research, as well as potential for future use as a digital shopping channel.

While the presented research provided the first step into validating shopper behaviour in immersive virtual stores using walk-around locomotion, it is still uncertain whether these findings apply to other available locomotion methods in immersive VR. Thus, the next chapter will examine two different locomotion methods and their impact on shopper emotions and behaviour in an immersive virtual store experiment.

3.1 Introduction

The development of motion-tracked immersive virtual reality offers tantalising possibilities for shopper research. Market researchers already use a variety of experimental tools to investigate new product preferences and in-store shopper behaviour, including test-markets (Reibstein & Chussil, 1999), physical simulated stores (Silk & Urban, 1978) and desktop-operated VSS[5] environments (Burke et al., 1992). While test-markets and physical simulated stores avoid the criticisms levied at surveys of consumers' stated intentions (Chandon, Morwitz, & Reinartz, 2005), such approaches are nevertheless costly and offer only limited controllability of the store environment (Burke, 1996). In contrast, virtual store experiments can be conducted rapidly, provide control over a multitude of environmental store variables and require less investment for store development and setup (Burke, 1996). Additionally, VSSs enable market researchers to observe and record shopper-product-interaction (e.g. the time a shopper handles a product or reads a package label) in an accurate and unobtrusive manner. These traits allow VSSs to provide ideal trade-off between cost efficiency and data quality that can significantly enhance market research practices.

The recent introduction of iVR[6] technology promises major improvements in user immersion in VSSs. Instead of conventional navigation via mouse and keyboard, iVR simulations use immersive hardware (such as head-mounted displays (HMDs), body-tracking sensors, and motion-tracked controllers enabling walkaround navigation) to make interactions between user and virtual environment more intuitive and natural. This naturalism leads to greater perceived telepresence compared to traditional desktop systems (Cummings & Bailenson, 2016; McGloin et al., 2011; Usoh et al., 1999). Telepresence, described as a feeling of 'being there' in the virtual environment (Witmer & Singer, 1998) is the extent to which a user accepts the virtual illusion of a real place. Importantly, Waterlander et al. (2015) report that greater telepresence improves the similarity between VSS purchases and actual shopper purchases.

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[5] **Virtual Simulated Store**

[6] **Immersive Virtual Reality**

Extending previous studies, Schnack, Wright and Holdershaw (2019) compared telepresence in a traditional desktop VSS with telepresence in an immersive VSS using the latest iVR technology. Their results confirmed that the iVR-generated store environment led to higher levels of telepresence compared to desktop technology, implying that VSSs using iVR technology (immersive VSS) will yield greater similarity between shoppers' virtual and actual shopping behaviours. Immersive VSS also allows simulation of a complete small-format retailer, with consumers able to engage in walkaround shopping trips with multicategory purchasing. The study of such complete shopping trips offers obvious advantages in the naturalism of the consumer experience, as well capacity for research on shopper flow, shelf height effects, unplanned purchasing, and so on. The flexibility of the format allows for easy implementation of variations between shopping environments, offering further obvious advantages for controlled experimentation.

However, to the authors' knowledge, there is currently no study that provides holistic documentation of shopper behavioural patterns in an immersive VSS environment. To address this gap, this study is the first to report observations of a diverse set of shopper metrics from a multicategory shopping trip in an immersive VR shopping trip. As similarities and differences between VSS and actual shopper behaviour have been quite well established for single category testing in desktop VSS shopping, we report a differentiated replication that checks some key results from the VSS literature, but also examines a broader set of in-store behaviours within an immersive VSS environment. This approach is similar to that of Anesbury, Nenycz-Thiel, Dawes, and Kennedy (2016), who documented online shopper behaviour in an exploratory manner, with benchmarks for validation drawn from prior work in the physical retailing literature. The results of the present study will indicate whether immersive VSS experiments lead to authentic shopper behaviour usable by market researchers and in consumer behaviour experiments.

Theoretical Background

Validation of shopper metrics in desktop VSSs

VSSs are sophisticated computer simulations designed to resemble real-world retail environments with the intent of creating believable in-store stimuli that lead to authentic shopper behaviour. While these systems have developed over time from simple desktop applications to more immersive CAVE (Cave Automatic Virtual Environment) or HMD supported systems, evidence about the validity of VSS shopping has principally been developed through desktop-operated systems.

The first study to compare consumer choices between VSSs and purchases in a real grocery store was published by Burke et al. (1992), who compared shopper metrics from textual descriptions and a pictorial simulated store with actual purchases in a physical store. Burke et al.'s results demonstrated that while VSSs are able to capture general brand preferences, some deviations were found in overall purchase quantity, reaction to price promotions, brand variety seeking and share of national brands. The authors concluded that, while behaviour in VSSs will never be entirely realistic, variation in shopper metrics arising from manipulated variables can still be reliably detected, highlighting the potential of virtual systems as a market research tool. Later, S. Cohen and Gadd (1996) developed a virtual version of a Canadian liquor store using self-reports of purchase behaviour as a benchmark. They also concluded that choices in the VSS matched participants' actual purchase patterns. Campo et al. (1999) used a similar design to Burke et al. (1992), and found that data collected with a virtual store environment was fairly similar to real-world purchases in terms of product market shares, but again reported some deviations in participants' specific behaviours. Similar results were found by Desmet et al. (2013), Van Herpen et al. (2016), as well as Waterlander et al. (2015) who compared metrics from their virtual supermarket to participants' actual weekly purchases in real supermarkets.

More recently the first immersive VR systems have been subject to some validation efforts. CAVE-based VSSs have been used to investigate whether real-world customer types can be found in a virtual shopping context and the results showed a significant overlap in the majority of investigated customer types (Khan & Brouwer, 2016). Another study using an HMD-based system by Pizzi, Scarpi, Pichierri, and Vannucci (2019) found strong similarities in subjective shopper perceptions, consumer orientations, and shopping behaviours between immersive VSS and physical retail setting. Although the research concluded that HMD-based iVR has the ability to effectively reproduce shopper in-store behaviour, findings were limited to a single product category.

Authors have also developed and used VSS experiments for consumer behaviour research. The first to do so were Van Herpen, Pieters, & Zeelenberg's (2005), who used a desktop-based VSS environment to examine shoppers' response to product scarcity in the wine category. Six years later Waterlander et al. (2011) showcased their 'Virtual Supermarket', a desktop-based VSS that could be remotely used from home and did not require participants to commute to a research facility. Waterlander et al. (2011) thenceforth used their VSS environment software to test a range of shopping related manipulations such as taxes and subsidies (Waterlander et al., 2012b), price discounts and health labels (Waterlander et al., 2012a, 2013) , and sugar taxes (Waterlander et al., 2014). Zhao, Huang, Spence, and Wan (2017) used an HMD-based VSS to investigate shoppers' in-store searching behaviour in the wine category. Furthermore, HMD simulations have been used to investigate consumer perceptions and behaviour toward misshaped fruits and vegetables (Verhulst et al., 2017) and consumer choices in the cereals category (Siegrist et al., 2019).

Others have used CAVE systems to investigate a range of shopper behaviours. For example, van't Riet et al. (2016) and Ketelaar et al. (2018) used a CAVE system to investigate the effect of location-based advertising on attitudes and the intention to buy the advertised product. Moreover, CAVE systems have been combined with eye-tracking to examine consumer choice, eye movement and store navigation (Bigné, Llinares, & Torrecilla, 2016), an approach that has also been discussed in detail by Meißner et al. (2017). However, by their nature, CAVE systems are unable to include all the immersive elements that are available from HMDs, such as full motion-tracked navigation and product selection using naturalistic actuators.

Collectively, the studies extending Burke et al.'s (1992) pioneering work provide some examples of applications of VSSs, and have established a methodological platform for observing consumers' in-store behaviour. Yet, despite the existing evidence supporting desktop-based VR, VSSs have yet not achieved widespread adoption as a research tool. This might be due to shortcomings with regards to shopper immersion and realism of the shopping experience. These downsides can potentially be addressed by more advanced immersive VR technology. Research exploring the validity of these new immersive VR VSSs is still scarce. Currently, evidence about shopper behaviour in immersive VSSs is limited to niche metrics of consumer behaviour (e.g. comparison of customer types, consumer perceptions and orientations) or to single product categories. A holistic investigation of basic shopping patterns across multiple product categories is still missing. Hence, it seems justified to explore the potential of iVR technology in a broader context and to shed light on to whether real-world behavioural patterns can be discovered in an immersive virtual convenience store context.

Shopper in-store behaviour in this study

In the present study, an exploratory approach is therefore taken to compare observations from an immersive VSS experiment with existing knowledge in the extant shopper behaviour literature. The investigations focus on metrics often used in shopper behaviour studies namely (a) the share of private label brands purchased (Hyman, Kopf, & Lee, 2010); (b) shopper responses to shelf positions (Hübner & Kuhn, 2012); (c) gender-related differences in total spending and shopping time (Davies & Bell, 1991); (d) the extent of unplanned purchases (Muruganantham & Bhakat, 2013); and (e) product handling times (Balasubramanian & Cole, 2002). Further details are as follows.

(a) Private label (PL) shares

Private label brands have become increasingly important as reflected by continual growth in markets such as the US and Europe (Reinders & Bartels, 2017). Accordingly, academic interest has been focused on this sector of retailing (Girard, Trapp, Pinar, Gulsoy, & Boyt, 2017). This has included research to validate PL shares in desktop VSSs; (Campo et al., 1999; Van Herpen et al., 2016) both confirmed that, for the tested categories, PL shares in a VSS resembled the physical benchmarks. The current study examines PL shares in five product categories in an immersive VSS. This initially replicates the aforementioned studies on PL shares in a VSS, and then extends the prior work to investigate whether PL shares also vary with the consumption pleasure associated with a product category. Previous findings show consumers are willing to pay a premium in product categories that deliver more consumption pleasure, and consequently tend to buy fewer PL brands in those categories (Ailawadi, Lehmann, & Neslin, 2003; Sethuraman & Cole, 1999), a finding also confirmed by Batra and Sinha (2000).

(b) Shelf positioning

Shelf space is seen as the most important in-store resource for retailers (Tsao et al., 2014) and evidence-based shelf space management is a crucial way to maximise profits in the retailing sector (Gajjar & Adil, 2011). Virtual retail environments offer a realistic replication of shelf displays that can easily be manipulated in various ways. Moreover, in contrast to frontal photographic stimuli predominantly used in surveys, products can be inspected in a more realistic way from changing angles (Van Herpen et al., 2016). Driven by this potential Van Herpen et al. (2016) engaged in validation of VSSs for shelf management research and compared purchase rates from different shelf levels between mock-up store, desktop VSS, and a photographic shelf display. Results showed that purchase rates between virtual store and mock-up store were much closer than between photographic stimuli and physical mock-up store. The current study replicates previous research into vertical shelf positioning in VSSs and extends it to consider both regular shelves and chiller units.

(c) Gender-related differences in purchase behaviour

It is important to understand whether there is a gender-related impact on purchase patterns in VSS experiments. For instance, Citrin, Stem, Spangenberg, and Clark (2003) found that, in the context of online shopping, females showed a higher need for tactile input than males. At present VSSs are not able to simulate tactile feedback of products, although they do allow selection and movement of products, including rotation. Nonetheless, shoppers cannot touch and feel the products offered in virtual shelf displays. This missing sensorial input could potentially reduce purchases by female shoppers, leading to underestimations of their total spending. Other gender differences in shopping that might be impacted in the context of the VSS environment include product inspection behaviour (Orquin & Scholderer, 2011) and time in-store (Sommer, Wynes, & Brinkley, 1992). To clarify whether the VSS environment reproduces gender-related differences in behaviour, the present study investigates whether total spending, in-store shopping time and product inspection times are congruent with patterns reported in the extant literature.

(d) Unplanned purchases

Research suggests that unplanned purchases make up to 76% of purchased products in the grocery sector (POPAI, 2014), thereby contributing a substantial share of retailers' profits (Inman & Winer, 1998; Mattila & Wirtz, 2008). Given retailers' desire to understand how to appeal to consumers' impulsive tendencies, extensive research has been undertaken into how in-store purchase decisions are made (Amos, Holmes, & Keneson, 2014). In this context Kacen, Hess, and Walker (2012) reported the importance of product and retail environment-related factors for stimulating impulse purchases. Specifically, they found that tactile (Citrin et al., 2003) and olfactory (Spangenberg, Crowley, & Henderson, 1996) cues can have a decisive impact on consumers' purchase decisions. A crucial question for researchers who intend to use VSS stores to investigate impulse purchase behaviour is whether a VSS environment that only conveys visual and audible stimuli can successfully simulate realistic product and retail environment-related factors that trigger unplanned purchases.

(e) Product handling times

Shoppers' product interactions with packaging design and responses to on-pack information is of much interest to marketers, however insights obtained from an actual shopping context are rare (Grunert & Wills, 2007). Experiments using VSS environments to investigate shopper behaviour in a holistic retail setting could address the current lack of real-world findings. However, it is first necessary to establish whether product stimuli delivered in a virtual setting lead to inspection behaviour that is similar to real-world behaviour. Of particular concern is that VSS shoppers may not associate any negative outcomes with the decisions they make as they do not have to consume or financially commit to the goods purchased. This lack of perceived risk could lead to reduced interest in reading labels, thereby limiting the feasibility of VSSs for research into on-pack labelling. In order to establish whether consumers in an immersive VSS do engage with on-pack information, the current study examines the occurrence and magnitude of product label inspection, including whether inspection varies between familiar and unfamiliar (fictional) brands.

3.3 Material and Methods

Research Design

Shopper metrics were collected in an immersive VSS previously reported in the literature (ViCoS 2.2; Schnack, Wright and Holdershaw, 2019). The virtual store contained products from 15 different food categories: potato chips, crackers, chocolate, ice cream, biscuits, confectionery, muesli bars, soft drinks, juices, fermented tea drinks, flavoured milk, baked beans, canned tomatoes, canned corn and canned tuna. Each product category had three to eight brands and a decent variety of different flavours. In general, selected brands, prices and shelf positioning were designed to resemble a New Zealand convenience store (see Figure 6). To achieve a close resemblance with the real-world store, selected products were based on local retailer stock lists, in-store images, followed up by a review by retail experts. Further, to enable comparison of the product inspection behaviour between familiar and non-familiar brands, one fictional brand unfamiliar in the New Zealand market was included in each of the ice cream and crackers categories.

The application employed a stereoscopic HMD (HTC Vive with Lighthouse Tracking Technology) and hand-held motion-tracked controllers provided by HTC Corp (see Figure 7). The two hand-held controllers were used to collect and hold a shopping basket and to interact with the products presented in virtual store shelves and chiller units. In order to create a highly realistic store environment, the VSS included a multitude of environmental sounds such as noises of fridge compressors, sliding fridge doors, passing pedestrians and cars outside the store, in-store advertising, product placement into the shopping basket, as well as the checkout operator typing on the cash register and talking to the participant.

Participants

The total sample comprised 153 participants aged from 13 to 77 years with a mean age of 34. Data were collected from two areas in New Zealand (Auckland, n=50; Palmerston North, n=103). Participants were recruited via street intercept, advertising in social media, convenience sampling techniques, with a small proportion also recruited by snowballing sampling to overcome funding and time constraints. Appendix C demonstrates the diverse demographic mix among the sample, albeit with a slight skew towards younger, educated, higher income consumers.

Figure 7: Inside the immersive VSS

Figure 6: Participant during VSS experiment

Experimental Procedure

This study followed the procedures outlined by Desmet et al. (2013). Before starting the shopping experiment participants received training in navigating inside the immersive VSS environment including how to interact with the virtual products. This training served to reduce initial levels of excitement caused by participants' exposure to iVR technology, and to ensure that all participants had a common level of immersive VSS experience prior to participating in the study.

For the simulated shopping trip, participants were given a written shopping list and a hypothetical scenario which required them to imagine that a friend or family member was expecting guests and needed some items from a nearby convenience store. This scenario was chosen in order to reduce the impact of participants' own demographic traits on the purchase decisions. The task suggested that purchases be made from some of the following product categories: ice cream, chocolate, fermented tea, flavoured milk, crackers, and baked beans. However, participants were not restricted to shop according to the list and could purchase from other product categories with no time restrictions imposed. In order to avoid any interruptions in perceived telepresence during the virtual shopping trip, participants were instructed to imagine that they are in an actual store, were spending real money, and that there are no other people around. Post-experimental interviews confirmed that most participants indeed perceived the immersive VSS as very realistic (see Appendix D). After the experiment participants recruited through street intercept were reimbursed with a 20 New Zealand Dollar gift voucher.

Measurements

Data recorded by the iVR application (ViCoS 2.2) for analysis includes total shopping time, total amount spent, basket size as well as detailed data about each handled product. For instance, it is determined when during the trip and from which shelf position a product was picked up, whether it is rotated more than 180 degrees, for how long it is attached to the controller, and whether it is placed into the shopping basket or back on the shelf.

Data Analysis

Statistical analysis is performed using the IBM SPSS Package Version 24. Metric data (e.g. shopping time, inspection time, amount spent) are assessed using the Shapiro-Wilk test for normality and a non-parametric equivalent of Levene's (1960) test for homogeneity of variances. Results indicate that the data violates the requirements of normal distribution and heteroscedasticity required for application of parametric statistical analysis. Hence, throughout this study deviations between group means are analysed using a Welch-Satterthwaite test as this technique is suggested as being robust to both violations (Zimmerman & Zumbo, 1992). Where statistical test results are equivocal, effect sizes are calculated using Cohen's d scores (J. Cohen, 1988). Moreover, differences in sample proportions (e.g. shelf position, gender percentages) are analysed using a Pearson's chi-square test.

3.4 Results

The following sections describe observations from the virtual store experiment and compare them with purchase patterns reported in the literature. For a detailed overview of published sources which provided benchmarks to compare shopper metrics, see Table 3. In making comparisons with prior literature, we are interested in determining whether the same theoretical effects can be detected as were found in prior studies. It is generally not possible to make statistical comparison of the underlying frequencies between studies, as the shopper populations or shopping channels examined vary between each study. That is, theoretical effects can be compared between studies statistically, but underlying frequencies cannot. Nonetheless, in the case of private labels and unplanned purchases, it is interesting to consider the magnitude of the measured frequencies to see whether they are plausible given previous findings. Thus, although statistical comparisons are not always meaningful, a qualitative comparison still speaks to the authenticity of the shopping experience.

Private label shares

Turning then to private labels, these were included in five of the categories used. Frequency analysis shows that PL brands account for 15.3 % of all purchases. This magnitude of PL purchases seems to be a realistic depiction, as figures by McNeill and Wyeth (2011) and Nielsen (2015) report a similar market share of grocery sales for PL brands in the New Zealand market, with 17% and 14% respectively. These results serve to illustrate the plausibility of the general magnitude of PL purchases in an immersive VSS experiment, and so provide initial support for the authenticity of shopper behaviour in this context.

Results for specific product categories show that PL market shares are higher for categories that are lower in consumption pleasure. The PL share for baked beans (28%), arguably the category with the lowest consumption pleasure of the categories examined, is significantly higher than PL shares in snack categories such as ice cream (14%), crackers (13%), biscuits (11%) and potato chips (5%) (see Figure 8). A row of pairwise Chi-Square tests further reinforces results by confirming that the difference in PL shares between baked beans and each snack food category is statistically significant for ice cream, χ^2 (1, 373) = 11.52, p < .01; crackers, χ^2 (1, 376) = 15.02, p < .01; biscuits, χ^2 (1, 219) = 6.37, p = .01; and potato chips, χ^2 (1, 302) = 27.87, p < .01. This result aligns with previous findings that consumers are willing to pay a premium in product categories that deliver more consumption pleasure, and consequently tend to buy fewer PL brands in those categories.

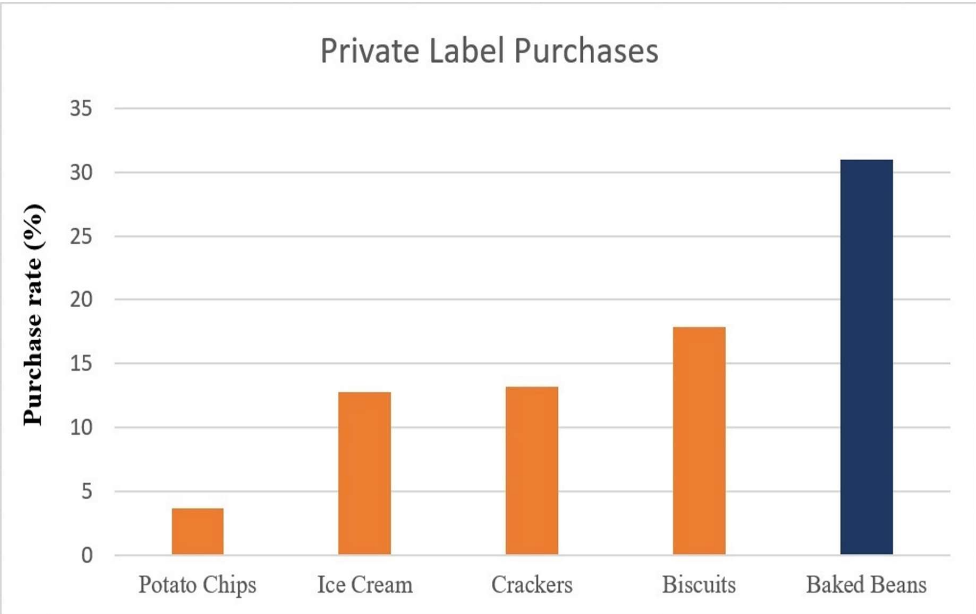

Figure 8: Private label purchase rates

Shelf positioning

The next analysis reports whether purchase rates differ depending on the vertical shelf level. The results are split between regular shelves (four shelf levels) and chiller units (three shelf levels). For the regular store shelves, purchase rates increase with higher shelf levels (see Figure 9). Fewer products are purchased from the bottom shelf level (9.6% of all purchases), than from the second to bottom shelf (12.7%). Whereas the third to bottom shelf (28.1%) and top shelf (eye-level) (49.6%) have significantly higher purchase rates. This result is confirmed by a chi-square analysis which found significant differences between the four shelf positions, χ^2 (3, 975) = 730.079, p < .01.

Table 3: Overview of benchmark shopper metrics

	Current findings	Benchmark	Source
Private label (PL) share	15.3% of sales carried a PL brand	PL market share in New Zealand is 14 - 17%	McNeill & Wyeth, 2011; Nielsen, 2015
PL share per category	Lower PL share in product categories with high consumption pleasure	Higher willingness to pay price premium in high consumption pleasure product categories	Ailawadi, Lehmann, & Neslin, 2003; Batra & Sinha, 2000; Gamliel & Herstein, 2007; Sathuraman & Cole, 1999
	PL share in the category potato chips 3.7%, and crackers 13.2%	Low PL shares in categories like cookies, potato chips and snacks (7.2% - 8.9%)	Akbay & Jones, 2005; Batra & Sinha, 2000
Shelf positioning	Increasing product purchase rates from bottom to eye-level shelf, with about 50% purchases from the eye-level shelf location	Top- and middle shelf position attract higher shopper attention, leading to higher purchase rate	Chandon, Morwitz, & Reinartz, 2005; Dreze, Hoch, & Purk, 1994; Valenzuela, Raghubir, & Mitakakis, 2013; Van Herpen, Van Hierop, & Sloot, 2012
Gender differences in purchase behaviour	Female total spending tended to be higher than males (*no significant difference*)	Females spend on average more money per grocery shopping trip than males	Davies & Bell, 1991; Mortimer & Weeks, 2011; Richbell & Kite, 2007; Slotterback & Oakes, 2000; Zeithaml, 1985
	Female task completion time tended to be longer than males (*no significant difference*)	Females spend on average more time per shopping trip than males	Davies & Bell, 1991; Mortimer & Weeks, 2011; Sommer, Wynes & Brinkley, 1992
	Females had on average longer product handling times	Females have stronger tendency to read product nutrition labelling	Guthrie et al. 1995, Ollberding, Wolf, & Contento, 2010; Orquin & Scholderer, 2011
Unplanned purchases	78.3% of shoppers purchased from a product category that was not suggested by the shopping list	93% of shoppers purchase from one or more product categories that are not on their shopping list	Thomas & Garland, 1996
	21.6% of total purchases were not from categories suggested by the shopping list provided by the task	13 – 70% of all purchases in convenience stores/supermarkets are unplanned	Inman & Weiner, 2009; Ruff, Akhund, & Adjoian, 2016; Kelly, Smith, & Hunt, 2000
Product handling time	Product handling time was significantly higher for fictional brands than for other actual brands	Brand signal reduces perceived risk of purchase/ Consumers search for less product information when encountering familiar brands	Erdem & Swait, 1998; Jacoby, Szybillo, & Busato-Schach, 1977

Store placement of chilled products reveals a very similar result. While participants purchase fewer products overall from the bottom shelf level (18.3%), both the mid-shelf (31.4%) and the eye-level shelf (50.3%) show much higher purchase rates. The chi-square test also confirmed this result, χ^2 (2, 761) = 118.623, $p < .01$.

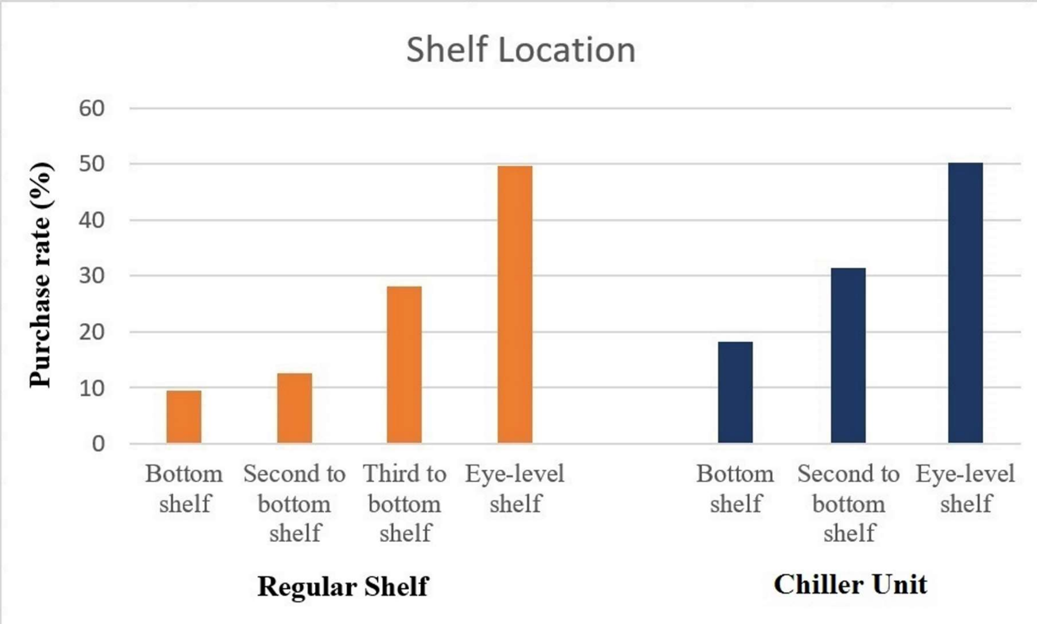

Figure 9: Purchase rates from shelf levels

Gender-related differences

The first gender-related difference considered is the total amount of money spent (see Table 4). Males spend on average NZD 41.86 in-store, while females spend on average NZD 44.78, consistent with prior literature showing women spend more in-store than men. However, the Welch-Satterthwaite test found that the group means are not significantly different, $F(1, 150) = 1.12$, $p = .29$; Cohen's $d = 0.17$.

Considering total time spent for the simulated shopping trip, males spend on average 4 minutes and 38 seconds for their shopping task, while females spend slightly more time with an average of 5 minutes and 14 seconds. As in the case of the total spending, while results on first glance confirm prior literature showing that females shop for longer, the Welch-Satterthwaite test could not detect a significant difference in means, $F(1, 150) = 2.38$, $p = .13$; Cohen's $d = 0.25$.

The same analysis is conducted for the time participants have a product attached to the controller (inspection time). Males have an average contact time with a product of

4.1 seconds, approximately 13% less than females with 4.85 seconds. The consecutive Welch-Satterthwaite test in this case did confirm a statistically significant difference between males and females, $F(1, 2131) = 7.68$, $p = .01$, with a fairly small effect size (Cohen's $d = 0.12$).

Table 4: Gender-related shopping metrics

	N	Mean	SD	Min	Max	*F*	*p*
Amount Spent[1]						1.122	0.291
Male	81	41.86	16.25	12.38	85.06		
Female	71	44.78	17.56	15.08	93.35		
Shopping Time[2]						1.454	0.230
Male	81	4:38	1:54	0:43	10:32		
Female	70*	5:03	2:20	1:06	10:46		
Inspection Time[3]						7.676	0.006
Male	1121	4.1	4.7	0.08	58.6		
Female	1012	4.7	5.9	0.19	73.5		

* *One case deleted because of extreme value*
[1] In New Zealand Dollars
[2] In minutes
[3] In seconds

Unplanned purchases

Considering purchases of items that fall outside the suggested categories for the shopping list, 22% of all purchases in the immersive VSS are of this type, and so can be regarded as unplanned. This result compares with an unplanned purchase rate of 13% reported by a recent study in a small US convenience store (Ruff, Akhund, & Adjoian, 2016).

Findings also indicate that 78% of shoppers make at least one unplanned purchase, and this resembles findings from prior research on shopping list usage in supermarkets, as Thomas and Garland (2004) found that 93% of shoppers exceeded the product categories specified on their shopping lists.

While the results on unplanned purchases cannot be statistically compared with the prior literature due to differences between countries or between shopping channels, they are nonetheless clearly of a similar magnitude. The results therefore indicate the plausibility of the immersive VSS shopping environment and its authenticity in allowing for the capture of unplanned purchases. This is in contrast to single category VSS studies, as these do not have any capability to measure unplanned purchases.

Product handling time

Dickson and Sawyer (1990) reported that shoppers spend on average less than 12 seconds in front of a category display. Similarly, analysis of product inspection behaviour in the VSS shows that participants spend very little time closely inspecting products before making a purchase decision. Across the 2128 interactions with products, participants spend on average 4.3 seconds to pick up a product and place it into their basket. An average time of 4.3 seconds for product handling seems plausible as this timeframe excludes visual evaluation of the shelf display, price comparison and observation of packaging in order to narrow down the set of considered products.

Analysis within product categories that include fictional brands reveals that inspection time does strongly differ between familiar and unfamiliar brands (see Table 5). While inspection time for the six real brands in the crackers category averages around 2.7 seconds, the inspection time for the fictional brand measures 8.5 seconds. Similar observations are found in the ice cream category with the inspection time of the fictional brand (11.8 seconds) exceeding the average inspection time of the other six brands (5.1 seconds). A pairwise comparison using a Welch-Satterthwaite confirms that mean inspection time of the fictional brand significantly differs from that of the familiar brands in both categories, crackers, $F(5, 252) = 6.35$, $p < .01$ and ice cream, $F(6, 352) = 2.94$, $p = .01$. These differences persist for each individual pairwise comparison (see Table 5).

Table 5: Product inspection times

	N	Mean (secs)	SD (secs)	Mean Difference* (secs)	*p*
Crackers					
Fantastic	14	2.0	1.9	6.5	<.01
Griffin's	30	2.1	1.6	6.4	<.01
Arnott's	73	2.7	2.6	5.8	<.01
Pam's	33	3.2	2.6	5.3	<.01
Huntley & Palmers	90	3.5	4.0	5.0	<.01
Fictional Brand	18	8.5	5.2	-	-
Ice cream					
Haagen-Dasz	49	4.2	4.9	7.6	<.01
Pam's	46	4.2	4.3	7.6	<.01
TipTop	87	5.0	7.0	6.8	<.01
Little Island	19	5.1	4.5	6.7	.01
Kapiti Coast	105	5.7	5.5	6.1	<.01
Like Licks	23	6.4	4.0	5.4	.03
Fictional Brand	30	11.8	11.1	-	-

* Difference in mean between each real brand and the fictional brand in the category, *p* values are for Tukey’s post-hoc test

3.5 Discussion and Implications

The results of the current study confirm the authenticity of shopper behaviour in an immersive VSS environment, highlighting the advantage of the designed iVR convenience store environment compared to previously used systems. To date, VSS solutions have either provided whole supermarket simulations operated on desktop systems (Bressoud, 2013; Van Herpen et al., 2016; Waterlander et al., 2015) or have used iVR technology to depict a confined shelf area for single category testing (Siegrist et al., 2019). The system presented in this paper goes beyond these existing approaches by creating a fully accessible virtual convenience store that combines a naturalist immersive walkaround experience with the ability to undertake multicategory testing. Recent research has shown that many aspects of shopper behaviour are generalisable across different store sizes and formats (Sorensen et al., 2017). Thus, it appears unreasonable to create a large-scale environment for testing product concepts or pack design, when such tests can take place more conveniently and cheaply in a smaller retail format using an immersive VSS.

Turning to the detailed results, we can note the following. First, the average basket gives a plausible magnitude for PL brand purchases, even though participants do not spend actual money for this exercise and could have exclusively selected premium options. Moreover, PL brands have lower purchase rates in product categories that are purchased for indulgence purposes than in categories with lower associated consumption pleasure. As there was no expectation of actually consuming a product, it is interesting to see that anticipated consumption pleasure still seemed to have a negative impact on purchases of PL brands. Collectively, these findings suggest that participants did consider price and taste in their decision-making, which indicates that they took the virtual shopping trip seriously.

On shelf positioning, the distribution of purchase rates across vertical shelves shows patterns that are congruent with previous research in physical environments, indicating a strong preference for eye-level (Dreze, Hoch, & Purk, 1994; Valenzuela, Raghubir, & Mitakakis, 2013). Similar responses to display characteristics have also been found for desktop-operated simulations (Van Herpen et al., 2016), however, immersive VSS has the potential to lead to more authentic shopper responses compared to desktop systems for two reasons. First, factoring in the physical movement and proprioceptive sense that is stimulated by iVR VSS hardware, these systems enhance perceived telepresence (Slater & Steed, 2000; Stassen & Smets, 1997) during shelf inspection, leading to more authentic shopper behaviour (Waterlander et al., 2015). Second, in immersive (walkaround) VR applications, participants see the shelf from their natural perspective as the software takes into account their actual height. Accordingly, eye-level varies between subjects within the sample as for regular shoppers in a physical store, rather than artificially giving all respondents the same virtual height as occurs in a desktop VSS.

Considering gender-related differences, women take more time than men to inspect products while also spending slightly more money in-store and taking slightly more time to complete the shopping trip. While only the first of these results is statistically significant, all three are in the expected direction based on existing knowledge (Davies & Bell, 1991; Mortimer & Weeks, 2011). To that end it is important to note that Cohen's *d* values for time taken and money spent are either above or close to the threshold usually deemed a small effect (d =.20), thus providing some support for the existence of gender-related differences in these aspects of shopper behaviour in the immersive VSS environment. Gender differences in inspection time may be due to females taking more time to consider on-pack nutrition information (Guthrie, Fox, Cleveland, & Welsh, 1995; Ollberding, Wolf, & Contento, 2011; Orquin & Scholderer, 2011) and having a higher need for tactile input when shopping than men (Citrin et al., 2003). Interestingly, the findings of this study indicate that use of an immersive VSS in which female shoppers could not actually touch and feel products did not eliminate gender effects in inspection behaviour. It may be that the need to consider product information and have tactile input is adequately addressed by the holistic authenticity of the shopping environment and the enhanced interactivity of the grasping and manipulation systems. Research which specifically addresses the role of tactile feedback, such as with use of haptic gloves, could further explore these aspects of gender-related differences in a VSS environment.

As noted in the results, participants do make unplanned purchases, and they also spend extra time for browsing and shopping in other product categories before finishing the experimental task. This implies that the experiment is not viewed simply as a 'computer game' requiring only completion of the experimental task. Instead, participants browse and purchase in a realistic manner, despite not expecting that they could physically consume any of their purchases. Hence, the results indicate that immersive VSS environments do have the capability to trigger unplanned (impulse) purchases, again due to the authenticity of the shopping environment.

Moreover, participants invest search time to examine products and read product labelling, as indicated by the fact that handling times for fictional products were on average significantly longer than for well established brands. It is assumed that this increase in handling time arose due to the absence of pre-existing brand associations that are known to reduce the need for product information acquisition (Jacoby, Szybillo, & Busato-Schach, 1977). Participants' perceived need to acquire product information before purchasing a new product indicates that a level of perceived risk was associated with the decision, despite there being no actual physical or financial risk associated with the virtual purchase. This finding suggests that VSS environments immerse shoppers to the extent of triggering actual decision-making, including perception of risk and associated product information acquisition.

Given the authenticity of the shopping behaviours found in this study, readers may naturally wish to know how similarly authentic shopping environments may be constructed. The immersive elements used to generate authentic shopper behaviour in the present study were high-resolution visual immersion with individual object modelling, naturalness of functionality for navigation and product inspection, extensive interactivity with the virtual environment, and an authentic audible environment (Schnack et al., 2019). Designers of VSS systems for shopper research may therefore be advised to include these elements by using: (a) HMDs that track head-movement and isolate a user's vision from the physical environment, creating a more convincing feeling of presence in the virtual environment (Hendrix & Barfield, 1996); (b) motion-tracked controllers allowing free product movement that improves naturalness compared to traditional mouse and keyboard interfaces (Seibert & Shafer, 2017); (c) body-tracking techniques based on actual locomotion, increasing the match between proprioceptive information and visual cues of the virtual environment (Slater, Usoh, & Steed, 1995); (d) actuators that allow the virtual shopper to manipulate each individual product and to interact with store elements such as fridge and freezer doors, the shopping basket and the store clerk, enhancing overall perception of interactivity (Animesh, Pinsonneault, Yang, & Oh, 2011;

Welch, Blackmon, Liu, Mellers, & Stark, 1996); and (e) a rich and realistic audible environment that completes the immersive experience (Dinh, Walker, Song, Kobayashi, & Hodges, 1999) such as electrical hums, background conversation, noise from passing traffic, and opening and closing sounds for chiller unit doors.

3.6 Limitations and Future Research

Our research examines a limited number of behavioural purchase metrics in specific product categories. Future research could extend this limited focus to a wider range of shopper metrics, such as dwell time, percent store coverage and feature/display effects. The present study is also limited to a specific set of categories and brands, and this restricts what can be said about variations between hedonic and utilitarian brands, or cross effects between complementary or substitute categories. Further, as much shopping occurs in larger store formats, it would be desirable to check whether the same results arise in fully stocked supermarkets. However, advances in immersive VSS hardware may be required to expand the simulation to accommodate many additional products or the formats of larger stores.

Research should also exploit the additional benefits that immersive VSSs offer compared to traditional tools. Now that the authenticity of the immersive VSS experience has been established, researchers can apply immersive VSS methodology to the investigation of problems in consumer behaviour such as how private label choices are formed within the store, the effect of horizontal shelf position or SKU density on choice, or the relationships between shelf dwell time, pack inspection and purchase. Other possibilities include the implementation of eye tracking cameras into HMD systems and using path tracking that allows creation of shopper flow maps and heat maps. These would simplify consumer research investigating shoppers' spatial movement and their handling and inspection of product packages.

Moreover, VSS experiments can be accompanied by more sophisticated tools used in Neuroscience such as EEG (Electroencephalogram) or EMG (Electromyography) to measure brain activity or facial expressions, providing additional insights into consumers' emotional responses to retail and product related stimuli. In the future, other sensory dimensions could also be added to the immersive VSS such as haptic feedback, odour, air quality and temperature. These opportunities emphasise the versatility and tremendous potential of immersive VSS systems for advanced market research.

Finally, given the authenticity of the shopping experience, it may be possible in the future to use immersive VSS as a genuine digital shopping channel. Such an application would require increases in home computer power, together with very efficient design of store locomotion to take account of limited space available for immersive VR in the typical home. However, these requirements do not seem insurmountable, and an immersive VSS shopping experience offers many advantages over the current predominantly catalogue-based approach to online retailing.

3.7 Conclusion

Research on desktop-operated VSS setups has previously found sufficient similarity to real-world shopper behaviour to enable their use for in-store experiments. A recent study (Schnack et al., 2019) indicated that immersive VR offers further improvements over desktop-operated VSS, as the resulting higher level of telepresence increases the authenticity of the measured shopper behaviour. However, the authenticity of the data obtained from a multicategory shopping trip in a fully immersive VSS remained unconfirmed.

The present study therefore compared shopping metrics from an immersive VSS with evidence from the academic literature to find (i) a plausible magnitude for PL purchases (ii) the existence and plausibility of shelf height effects (iii) the occurrence of minor gender-related differences in purchase patterns (iv) the occurrence of unplanned (impulse) purchases and (v) differences in product inspection behaviour between familiar and unfamiliar products. The most obvious explanation for these consistencies is that the in-store purchase patterns in the immersive VSS environment are an authentic analogue of real-world shopper behaviour. In fact, it is difficult to ascribe any competing explanation to these results.

Our work therefore makes a critical contribution by providing the first evidence of the authenticity of immersive VSS shopper behaviour in a multicategory shopping trip. The results also highlight possibilities for innovative research ideas, as VSS methodology enables the measurement of a wide range of purchase metrics that traditional methods cannot easily replicate. The methodology seems to bridge the gap between the traditional surveys, desktop experiments, and full test-market initiatives, as it provides an ideal trade-off of cost-efficiency and data quality.

The encouraging results of the present study therefore give greater confidence for further adoption of VSSs, and particularly immersive VSSs, to exploit these unique research capabilities. Much further research into this innovative area of market research is justified: to continue to advance VSS methodologies, to undertake more commercial and academic applications of VSS technologies, and even to provide insights into how consumers may one day use immersive VSS as a digital shopping channel.

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STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Alexander
Name/title of Primary Supervisor:	Schnack
Name of Research Output and full reference:	
An exploratory investigation of shopper behaviour in an immersive virtual reality store	
In which Chapter is the Manuscript /Published work:	Chapter 3
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	60
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Literature review, building virtual environment, planning experimental design, data collection and data analysis, writing manuscript first draft, preparing manuscript artwork, contributing to manuscript revisions and correspondence with reviewers.	
For manuscripts intended for publication please indicate target journal:	
Journal of Consumer Behaviour	
Candidate's Signature:	Alexander Schnack Digitally signed by Alexander Schnack Date: 2020.01.16 13:52:05 +13'00'
Date:	16/01/2020
Primary Supervisor's Signature:	Malcolm John Wright Digitally signed by Malcolm John Wright Date: 2020.02.17 12:26:35 +13'00'
Date:	

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Chapter 4: Does the locomotion technique matter in immersive virtual store environments?

Extended abstract

The previous chapters 2 and 3 highlighted the potential of immersive walk-around VR technology to advance the use of virtual simulated stores in market research. The overall conclusion is that immersive walk-around VR systems seem to be superior to traditionally used desktop-operated systems and that observed behavioural patterns were congruent with the marketing literature. The research presented in this chapter will expand on the previous chapters by investigating the role of shopper locomotion in virtual simulated store environments. There are currently a multitude of locomotion techniques for avatar locomotion available in the market, however, no research yet has examined how their use potentially impacts the outcome of virtual simulated store experiments. Thus, it is not certain whether the findings in the previous chapters 2 and 3 would apply to all types of locomotion techniques available.

This lack of knowledge is addressed by the research paper presented in this chapter which has the key aim to investigate whether controller-based avatar locomotion, in absence of physical walking, impacts and thus potentially biases shopper emotions and behaviour in immersive virtual reality store experiments. Currently one of the most prominent controller-based locomotion techniques is instant teleportation. An intriguing benefit of this locomotion technique is that it is likely to be cheaper to implement than the more naturalistic physical-walking locomotion technique that was used in the preceding chapters 2 and 3. It further enables use of larger store formats, as no equally scaled physical tracking area is required for the shopper to traverse the virtual store. However, these benefits come with some costs with regards to the naturalism of in-store locomotion, as the absence of physical walking reduces the realism of the virtual shopping experience.

To investigate a potential impact of this lack of physical walking, the present research compares shopper emotions and behaviour by applying a split sample experiment in a purpose-built immersive VR convenience store. Shoppers' emotional

states (engagement, excitement and stress, measured through electroencephalography), store coverage (represented by heat maps) and purchase behaviour metrics, are recorded during a virtual shopping task and compared between instant teleportation and physical walking locomotion techniques.

Results demonstrate that the absence of physical walking had no impact on emotional states or the investigated shopping outcomes. While instant teleportation led to some skipped shelf sections, there was no impact observed on the number of unplanned purchases. It is hence concluded that instant teleportation, currently the most popular locomotion technique in the VR gaming industry, is similarly suited to VR shopper research in small store formats. To the extent that the naturalism of immersive VR relies on proprioceptive engagement or embodied cognition, this appears to be adequately supported by upper body movements that do not require physical walking.

The findings discussed in this chapter provide fresh insights for the design of Virtual Reality shopping environments and highlight the validity and cost-saving potential of controller-based locomotion techniques in immersive VR store environments. This has valuable implications for VR market researchers and developers of future online-retailing platforms alike.

4.1 Introduction

Emergence of Virtual Reality in Marketing Research

Marketers are increasingly taking notice of the potential for Virtual Reality (VR) technology as a tool both for market research and to enhance customer engagement in the purchase process. Improvements in VR technology present new opportunities to conduct research in a naturalistic setting, to obtain data not previously available to researchers, to achieve cost-saving advantages, and to enable customers to interact with hypothetical scenarios. Hence it is important to advance knowledge on the use of VR technology by shoppers to guide the development and implemention of VR environments in marketing practice.

The significant recent change in VR has been the introduction of immersive virtual reality. This is a groundbreaking technology that uses computer hardware to immerse a user into an almost life-like experience in a computer-generated space. Commonly immersive VR experiences use head-mounted displays (HMDs) and headphones to isolate the user's senses from physical surroundings and trick them into an illusion of being in a different place. Motion-tracked hand-held controllers and locomotion via body-tracking allow users to move in and interact with the virtual environment in a way they would act in the physical world, making the experience remarkably immersive and realistic.

While early immersive VR technology was not advanced enough to cater for the mass market adoption, recent technological advances have expanded opportunities to utilise immersive VR as a commerical reseach tool. The first generation of HMDs were very bulky, uncomfortable to wear and delivered low image quality (Powers & Melissa, 1994). These factors and the additional tremendous price tag prevented HMDs reaching the low-end consumer market and VR was condemned to remain a purely scientific tool. However, thanks to significant improvements in display technology, HMDs became lighter, more compact and much cheaper to produce (Hoberman, Krum, Suma, & Bolas, 2012). Thus, since 2015 VR has seen an astonishing revival, becoming a popular buzz word in the media and is likely to find widespread mass market appeal, becoming a life-changing technology.

Public interest in VR mostly revolves around applications in video-gaming and the wider entertainment industry. Nevertheless, further opportunities beckon for education, training, tourism, marketing research and virtual shopping. One particularly interesting application is the use of VR technology as a platform for experimental virtual store research.

The Rise of Virtual Simulated Stores

Concerns about the validity of subjective measures of consumer preference and choice (Sheeran, 2002) led to an exploration of observational measures of consumer behaviour. One well-established method was to conduct shopper research in actual retail outlets (test market initiatives), however, the high cost, limited controllability and reliance on retailer collaboration were crucial limitations that made this methodology unaffordable for many market researchers (for a detailed discussion see Burke (1996)). A second, more cost-effective, approach was using observations of human behaviour in virtual generated environments, a technique that saw increasing application in the field of psychology for the last two decades (Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015).

The first reported use of such technology in marketing research was a software called *Visionary Shopper* developed and patented by Prof Raymond Burke of the University of Indiana, Bloomington (Gold, 1993). Obviously, the first generation of virtual stores was not as sophisticated and immersive as today's state-of-the-art VR environments. *Visionary Shopper* used a trackball to enable the user to browse through a virtual shelf, pick up and inspect products and to select items for purchase on a desktop monitor. This approach allowed the researcher to draw conclusions from objective observations of shopper behaviour instead of relying on subjective measures derived from consumer feedback. Consequently, a number of academic studies have used the virtual store methodology to investigate in-store shopper behaviour (Bressoud, 2013; S. Cohen & Gadd, 1996; Desmet et al., 2013; Van Herpen et al., 2005; Waterlander et al., 2014) and similar desktop-based approaches found widespread use in the commercial world (Breen, 2009).

It took until recently for these virtual store environments to reach the next developmental stage. After the release of mass-marketed HMDs in 2015, researchers started using this cutting-edge technology to move the user away from only witnessing the shopping experience on a screen to actually immersing them into it. The first applications of HMDs in marketing research, however, did not really use them to their full potential. For instance, a study by Verhulst et al. (2017) only allowed the user to move their avatar by using a video-game controller while being seated in a chair, which involved very little body movement. Later, more naturalistic systems used body-tracking technology for avatar navigation by physical walking (Schnack et al., 2019; Siegrist et al., 2019). However, this approach drastically restricted the accessible store space. Another technique that combines the features of body movement with the ability to traverse a large-scale store environment is instant teleportation. While this technique is very common in the VR entertainment industry, to date application of instant teleportation in a marketing research context is limited.

Embodied Cognition **and the impact of body movement on decision-making**

While there are a number of different potential locomotion techniques for VR store environments, an important question has yet to be addressed:

Does the locomotion technique potentially impact shopper decision-making?

It seems legitimate to ask this question, considering the large amount of evidence for a functional relationship occurring between motor and cognitive processes (Leisman, Moustafa, & Shafir, 2016). This relationship is conceptualised in the theory of *embodied cognition* (Shapiro, 2019) and gained increasing interest in the area of marketing research. In fact, marketers started researching the impact of bodily states on shopper decision-making and showed that bodily experiences are an essential part of how a shopper evaluates a product in-store (Eelen, Dewitte, & Warlop, 2013). This is due to the fact that action cues that occur when information is processed have the power to facilitate or inhibit decision making (Dijkstra, Kaschak, & Zwaan, 2007; Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001). For example, research showed that consumers perceived a food product as more pleasant if they imagined moving towards it (Labroo & Nielsen, 2009). Moreover, motor actions have been shown to affect the retrieval of memories and their associated emotional content (Casasanto & Dijkstra, 2010). Specifically, walking has been shown to stimulate creative thinking (Oppezzo & Schwartz, 2014), number processing (Anelli, Lugli, Baroni, Borghi, & Nicoletti, 2014), executive functions in elderly (Scherder et al., 2014) and the regulation of emotions (Shafir, Tsachor, & Welch, 2016). Based on this evidence it is expected that the presence, or absence for that matter, of physical walking can impact shopper emotions and thus decision-making, causing potential biases in observed shopper behaviour.

Impact of locomotion techniques in virtual stores on shopper behaviour

Embodied cognition theory hence implies that locomotion techniques in virtual simulated stores that involve whole body movement, for instance the physical walking technique employing motion-tracking, create a sensorial experience that is the closest to the natural experience of shopping in a physical retail environment.

It is accordingly expected that this locomotion technique delivers the closest replication of authentic in-store shopper behaviour, for example, of shopper decision-making and store navigation patterns. Unfortunately, a caveat of this technique is that it requires a physical floor space that is identical in scale to the simulated retail space. This compromises its feasability for shopper studies in larger retail formats, such as for whole supermarkets, and offsets the cost-saving potential of this methodology.

For larger store environments the instant teleportation method seems to be an attractive alternative. This method requires the user to stand in a stationary position and to use a virtual pointer to target a location and press a button to trigger an instant teleportation to the desired place (Boletsis, 2017). Unlike the use of traditional video-gaming controllers, this method uses motion-tracked controllers that allow the user to naturally interact with shelf facings and to stretch out or bend down to high or low shelf levels. This method is cost-effective as it requires little physical space for virtual store setups.

Considering the multitude of available navigation techniques, it seems important to understand whether the chosen technique alters how the user behaves in the virtual environment. Specifically, the absence of physical walking might have implications for purchase decisions in virtual simulated store experiments.

Goal of the current study

The current study is the first to investigate two immersive VR navigation techniques, physical walking and instant teleportation, in a simulated shopping context. The study will clarify whether the instant teleportation technique, that does not involve the act of physically walking through the virtual environment, is a feasible alternative to the more realistic physical walking technique in the context of virtual shopping. This question is answered by investigating:

The extent to which using the instant teleportation technique leads to emotional states and behavioural patterns that differ from the physical walking technique.

Results of this research will help marketers understand the role of physical walking in purchase decision-making and provide insights into how purchases are made if products are not approached by physical walking. This knowledge will inform marketers about potential limitations of the instant teleportation technique in simulated store experiments and whether application of more costly alternative techniques is required.

The study will further showcase the overall utility of cutting-edge technologies such as Virtual Reality retail environments and Biometric techniques such as Electroencephalography (EEG). These tools do not only allow detailed observations of shopper behaviour in naturalistic shopping environments but also provide objective measurements of shopper emotions during in-store shopping experiments. This paper hence provides a platform to move research away from criticised subjective measurements of emotional responses, such as surveys, that are currently still prevalent in the market research industry.

Besides providing relevant knowledge for marketers, insights will be useful for retailers who are looking for an alternative to traditional 2D online shopping platforms and who are interested in exploring 3D environments as an innovative sales channel. Allowing the consumer to access a three-dimensional virtual shop can revolutionise the way people buy online with delivery of a more immersive multi-sensory online-shopping experience (Speicher, Cucerca, & Krüger, 2017). Knowledge about the impact of locomotion techniques in that context can help retailers to design their online-shopping platforms in a way that appropriately manages the trade-off between technical affordability and the consumer experience.

4.2 Research Design

To empirically test the impact of locomotion on shopper emotions and purchase behaviour, a shopping experiment in a three-dimensional (3D) virtual convenience store was conducted. The convenience store environment was developed by the authors using the UnrealEngine4 game development software (Epic Games, United States). The virtual store application was installed and operated on a Windows 10 desktop computer with high performance graphics card. The computer was connected to an HTC Vive head-mounted display (HMD) that was strapped in front of the user's face. Interaction with products was performed using motion-tracked, hand-held controllers (HTC Corporation, Taiwan) that acted as a user's virtual hands and allowed handling of objects in the virtual space. Experimental Group 1 (EG1) used a physical walking (PW) technique to move within the virtual store. In this group a participant's physical position was tracked by two motion sensors (Lighthouse 1.0 tracking system, Valve Corp., United States) and any repositioning within the confined tracking area led to an equivalent movement within the virtual space. Shelf interaction was like in a physical store, requiring manual pick up of products and bending down to reach products on lower shelves. In contrast, Experimental Group 2 (EG2) was standing in a stationary position in the physical space and traversed the virtual store via instant teleportation (IT) using the hand-held controllers. A multi-function trackpad was used to activate a virtual pointer which was directed at the location on the floor a participant chose to teleport to (see Figure 10). Once the participant reached a shelf, interaction with products was identical to the physical walking group.

Figure 10: Store navigation via teleportation

The 3D Virtual Store Environment

The virtual store covered a floor space of four by four meters and included three shelves (of which two shelves were double-sided), one end-of-aisle shelf, two fridges, one chest freezer unit, one magazine rack, a check-out counter and an animated store assistant (see

Figure 11, floor plan). This retail space was stocked with 19 product categories including chocolate blocks (five brands), chocolate bars (eight brands), biscuits (six brands), chewing gum (one brand), sweets (two brands), muesli bars (seven brands), crackers (six brands), potato chips (five brands), ice cream (seven brands), canned baked beans (four brands), canned chopped tomatoes (four brands), canned corn (two brands), bread (three brands), milk (two brands), flavoured milk (five brands), soft drinks (four brands), fermented tea drinks (four brands), juice (three brands) and magazines. The product assortment and prices were based on a local New Zealand convenience store and were approved by local retail experts. Prices were displayed on tags attached to the shelf below each product. Products were selected by clutching with a virtual hand. Once attached to the virtual hand a product could be moved and rotated to allow closer inspection of relevant product-related information (e.g. nutritional facts). Products selected for purchase were placed in a virtual shopping basket and to complete the shopping trip, the participant placed the basket in a marked area on the check-out counter. Once the basket is in place the time spent for shopping was logged and the final list of purchased items recorded.

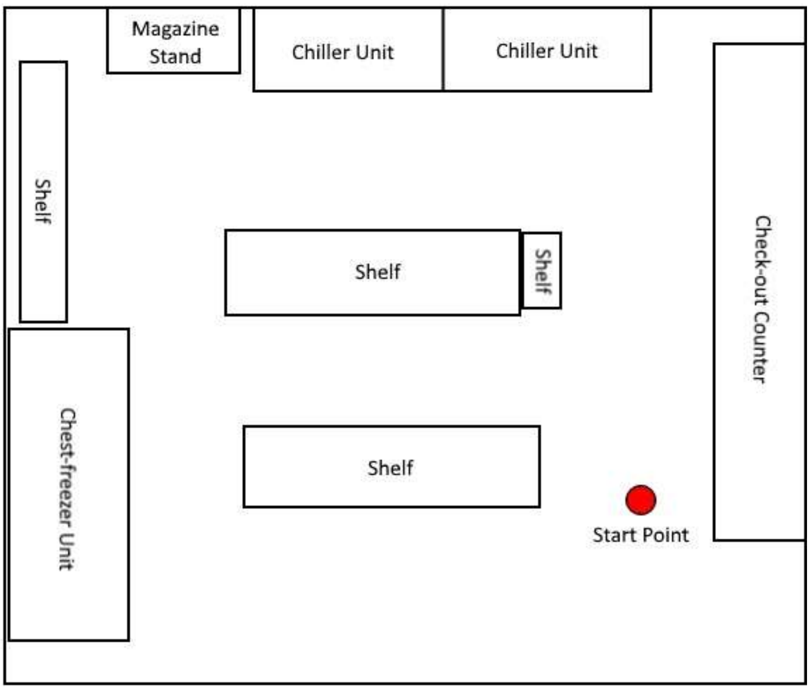

Figure 11: Floorplan of virtual convenience store

Procedures

Participants received a brief introductory session that outlined details of the study. After giving consent to participate, participants answered demographic questions and were then allocated to one of two experimental groups (EG1 or EG2). Subsequently, respondents were fitted with the EEG headset followed by calibration of the EEG sensors. After the headset was in place and calibration completed, participants were invited to relax for five minutes during which time the baseline levels of the three emotional states (engagement, excitement and stress) were obtained. Participants were then given an instruction sheet outlining the controller functions for the VR store environment, set up with the HMD, and undertook a standardised training and familiarisation session in a virtual training room. This session included practising moving in the virtual space and interacting with the virtual store fit-out and products. When comfortable with the use of the controller, participants received instructions for the shopping experiment. The task involved imagining receiving an invitation to a social gathering by a friend or family member and being asked to bring snack items from two product categories (crackers and soft drinks) for the host. Participants were further encouraged to purchase any other items they would like to enjoy at the event. Two further conditions were that the items had to suffice for four people and to imagine spending their own money for the purchase. For the exact task description please see Appendix E. The shopping experiment, like the training, was then carried out in a climate controlled room with a measured room temperature of between 20.6 and 23.7°C. The entire data set was collected only during summer months in the hours between 10am and 3pm to avoid any variation of climate or day time related factors and a resulting impact on participants' mood or purchase behaviour. While the shopping task was carried out we recorded participants' EEG readings and the investigated shopping trip metrics. After the shopping task was finished we asked participants to complete a final questionnaire containing some questions about prior brand familiarity (see Appendix J). The whole procedure took on average between 40 and 50 minutes and no compensation for participation was provided.

Sample

A convenience sampling approach was used, mainly recruiting from university staff, students and affiliates. However, in order to qualify for the study participants had to confirm that they were not wearing a cardiac pacemaker or any other medical device as

HMDs can emit radio waves that potentially interfere with the operation of nearby electronic devices. They also had to wear comfortable footwear that did not impair their ability to physically walk. Furthermore, to eliminate any confounding factors that might derive from participants' demographic characteristics a sample matching approach was used to achieve an equal age, education, income and gender distribution across both groups. Additionally, prior to the experiment participants were asked whether they had previous experience with VR technology, as it was expected that a pre-existing exposure could potentially impact excitement and stress, as well as the ability to learn and execute movement inside the VR environment. This information was used to ensure that both samples had roughly equal proportions of VR novices and experienced users. The final sample consisted of 71 participants, 35 in the PW group and 36 in the IT group. Across both samples we recruited a total of 34 female (47.9%) and 37 male (52.1%) subjects with a mean age of 37 years. For a detailed description of the two sub-samples please refer to Appendix F.

Measurements

Emotional States

Emotional states were recorded by using the wireless Emotiv EPOC+ EEG headset (see Figure 12). The EPOC+ system uses 14 wettened felt sensors that are positioned on the user's scalp located at 6 antero-frontal (AF3, AF4, F3, F4, F7, F8), 2 fronto-central (FC5, FC6), 2 occipital (O1, O2), 2 parietal (P7, P8) and 2 temporal (T7, T8) sites, as specified

Figure 12: Emotiv EPOC+ EEG headset

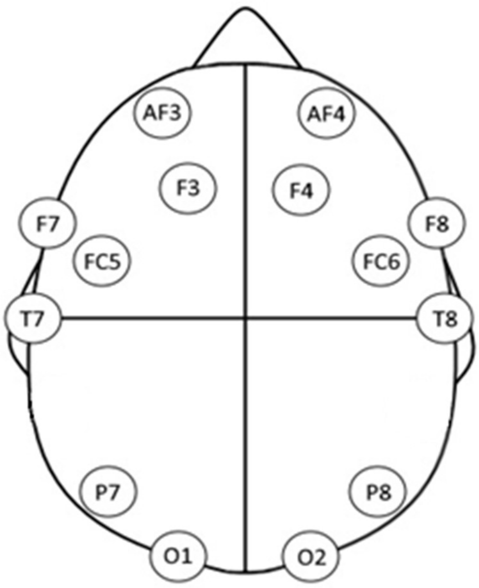

Figure 13: Locations of EEG sensors

by the international 10-20 system (Jasper, 1958) (see Figure 13). More detailed information about the Emotiv Epoc+ headset can be found elsewhere (Kotowski, Stapor, Leski, & Kotas, 2018). For EEG data collection an EmotivPRO v1.8.0 software suite was used to record raw EEG readings with a sampling rate of 128 Hz. The raw data is used by the software to ascertain emotional states (internally called *performance metrics*) using a proprietary algorithm (Cernea, Olech, Ebert, & Kerren, 2011). The three emotions that were used in this study are engagement (i.e. alertness), excitement (i.e. arousal of short duration) and stress (i.e. disappointment or cognitive load). For each participant, a pre-shopping experience EEG recording was obtained for the purpose of providing a baseline initial calibration measure for each emotional state, with values ranging between 0 (minimum) and 1 (maximum).

Once each participant commenced the shopping experience, an EEG measure of the strength of each emotional state was recorded every 10 seconds and displayed as a rescaled value between 0 and 1. This means that measurements of each participant's emotional state obtained during the shopping experience are interpreted in relation to the estimated prior values obtained. For instance, a value of 0.6 for the emotion of stress measured during the shopping process would indicate that a participant is experiencing 60% of their maximum stress level that was estimated by the software's initial calibration process.

Shopper Behavioural Metrics

Shoppers' behavioural metrics were recorded via a plug-in that was integrated into the virtual store software application. All relevant data was saved in the form of a data sheet in CSV file format and included detailed numeric information about a user's interaction with the products in-store (see Appendix G). For the current study shopping metrics in focus were trip duration (or time in store), basket size (or number of purchases), proportion of private label purchases, proportional purchases of unfamiliar products, and purchase rates from different shelf levels.

Path Tracking Data

The path consumers took when moving through the store was tracked using the tracking information the HTC Vive HMD operated on. The used software recorded the headset's position in a one second interval and marked each recorded position on a digital floor plan. This did not only allow visualising the exact route taken through the store but also enabled the researcher to determine dwell time at any location inside the store, simply by taking the number of consecutive data points at the same position. This additional information was used to create heat maps of the aggregated data that highlighted specific points of interest inside the virtual store. The heat maps were colour coded with red areas indicating spots with the highest proportion of tracking points (dwell time), yellow for the second largest, green and blue for areas with the fewest number of data points.

4.3 Results and Discussion

The first part of this section provides an initial descriptive analysis of overall emotional levels of engagement, excitement and stress measured with the Emotiv EPOC+ EEG headset. Next, we examine the role of the locomotion technique and report findings about its impact on participant emotions on both an aggregated and granular level. The comparison of the two locomotion techniques is then extended to observed shopper behaviour. Metrics including shopping trip duration, basket size, store coverage, proportion of private label purchases, proportion of unfamiliar product purchases, proportion of unplanned purchases, and product handling times were used to analyse participants' behavioural patterns. Lastly, we report whether the locomotion technique had an influence on participant store movement and dwell time patterns.

Descriptives of Overall Shopper Emotions

Figure 14 illustrates values for each emotion as an average across all participants. Results indicate that while shopping, participants experienced comparatively high levels of stress and engagement, while being only mildly excited. These findings align with research published by Baker and Wakefield (2012) suggesting that grocery shopping, a form of task-based shopping, is not a very exciting experience for a shopper. This was reflected by the moderate average excitement of 0.37 observed in the data. While it was expected that the novelty of the VR technology would cause a significant increase in excitement, the effect does not seem to be strong enough to make the shopping experiment an exciting

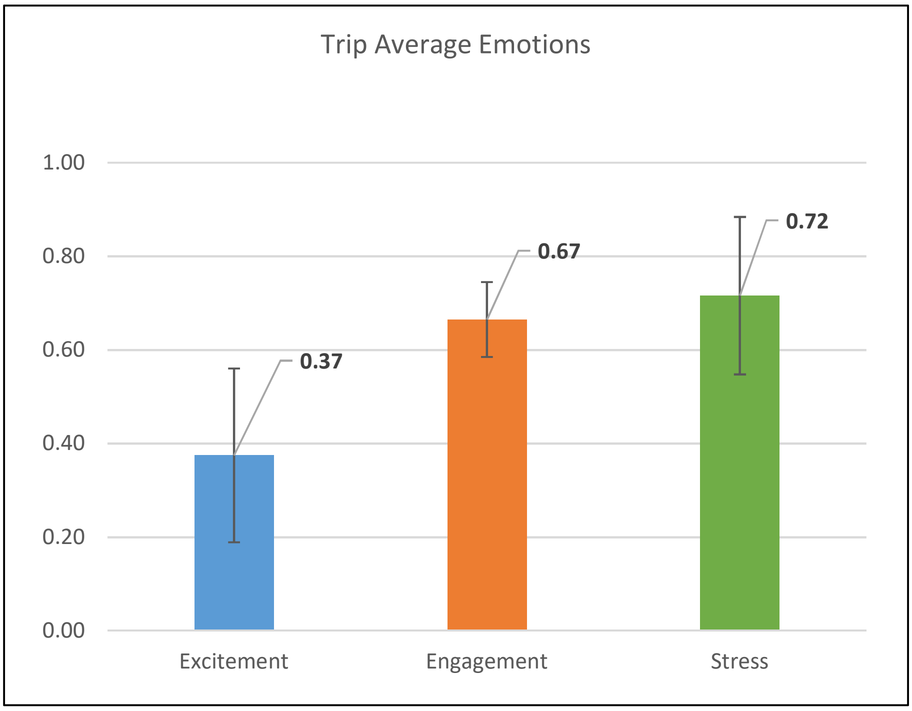

Figure 14: Average emotional strength of the sample

event on a physiologically measurable level. A possible reason is that shoppers were more focused on completing the shopping task than being able to enjoy the VR experience, which could underline the immersiveness of the system. It is hence concluded that VR usage does not seem to generate a large amount of technology related excitement.

When looking at engagement, an average level of 0.67 confirms research suggesting that immersive elements of VR technology are capable of creating high shopper engagement in VSSs (Violante, Vezzetti, & Piazzolla, 2019). According to Li, Daugherty, and Biocca (2001). High engagement in virtual environments is achieved if three-dimensional products are presented with a high degree of visual translation/rotation (the ability to zoom-in, rotate and view the product from different angles), contextualisation (the realism of the context the product is presented in) and stereopsis (depth perception). All these elements were incoporated in the design of the VSS used for this study. Products could be picked up and viewed from all angles, products were presented on a shelf in a detailed store environment that allowed interaction with store fit-out and the used HMD provided stereoscopic vision. These observations hence confirm previous research and suggest that those three elements are potentially an important driver for shopper engagement in virtual simulated store environments.

It was further found that participants were stressed by the virtual shopping exercise with an average stress level of 0.72. Thereby, two main factors are suggested that might be responsible for this elevated stress level. The first potential factor could be the use of an imposed shopping task in this experiment. Prior research reported that shoppers‘ experience added stress when facing a shopping task compared to recreational shopping situations (Baker & Wakefield, 2012; M. A. Jones, 1999). While a certain extent of stress is certainly natural and even occurs when a shopping task is self-imposed (using a shopping list based on home stock), this effect might be further enhanced if a shopping list is imposed by a third party and no positive outcome from the shopping is anticipated (e.g. no hedonic consumption of goods). Hence an experimental shopping task that imposes certain product categories could potentially increase stress levels that might negatively impact the validity of shopping experiments. This seems to be a reasonable notion as previous literature reported a substantial impact of perceived stressfulness of the shopping trip on shoppers’ attidudes and behaviour (Aylott & Mitchell, 1998; Moschis, 2007; Roy Dholakia & Uusitalo, 2002). Another factor that could be a potential reason for the increase in perceived stress is the learning process required to use controllers for interaction with the virtual store environment. However, it is expected that this effect declines as users get more familiar and proficient with the control interface over time. Nevertheless, results show the potential for elevated stress levels and indicate the need for further investigation.

When looking into changes in emotions on a more granular level (in different phases of the shopping trip) the findings revealed some interesting patterns with regards to stress and excitement. Figure 15 depicts means of stress and excitement that have been calculated for six stages. Each stage represents the average of three contiguous EEG measurements totalling 30 seconds of shopping. The stages are grouped into start, mid and end trip phases. The start trip phase covers the first 60 seconds of the shopping trip. The mid trip phase covers the two stages in the middle of the shopping trip. Since the shopping trips varied in length between participants, the mid trip phase was determined by splitting total shopping time in half, and taking the last stage of the first half (stage 3) and the first stage of the second half (stage 4). Lastly, the end trip phase marks covers the last 60 seconds of the shopping trip.

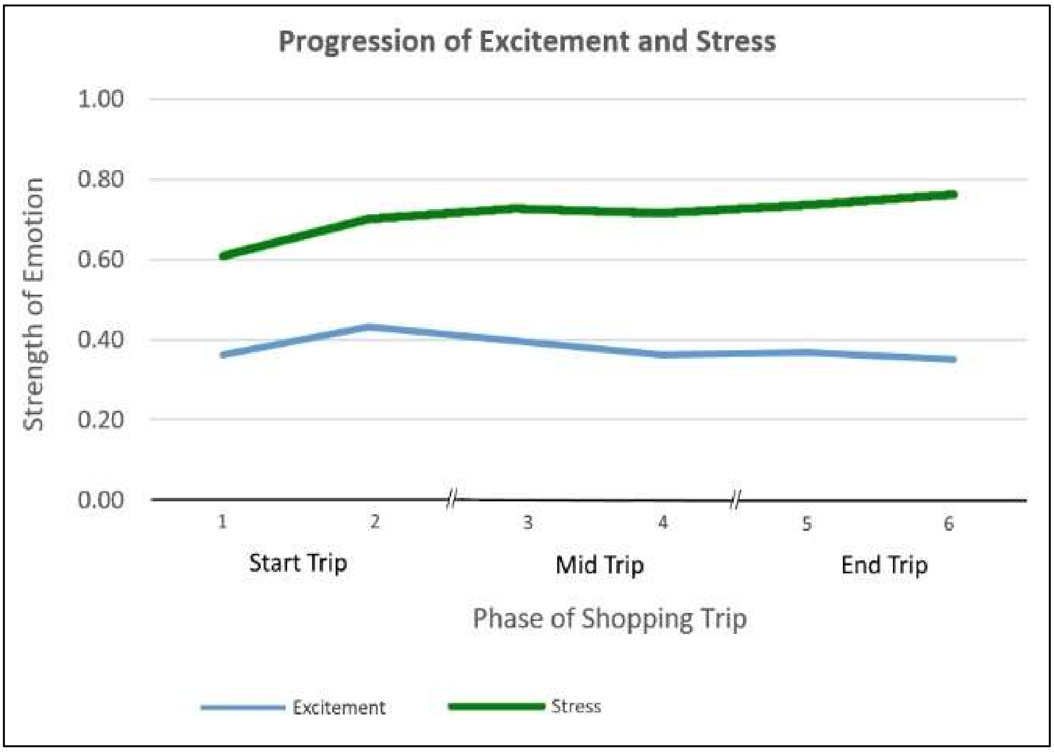

Figure 15: Stress and excitement levels

The graph shows that stress levels steadily increase (with a plateau during the mid phase) throughout the whole shopping trip, while excitement peaked in the late start phase and showed a steady decline until the end of the shopping. To get a more accurate approximation of the timing original readings that were recorded in an interval of 10 seconds were analysed and it was found that the excitement peak occured at around 40 seconds before it gradually decreased and stabilised (see Figure 16). While the current results cannot contribute to understanding the potential reasons for this occuring pattern in excitement, it is speculated that it could potentially be related to VR technology use and marking the point when initial VR technology related excitement was neutralised by the mundaneness of the shopping task. Or in other words, the point when immersion reached a threshold at which participants forgot about wearing an HMD and switched to shopping mode.

Figure 16: Peak in excitement at late start phase

Effect of Locomotion Technique on Emotional States (EEG)

This section reports findings on the relationship between the locomotion technique and EEG recorded emotional states. The analysis first compared the two locomotion techniques and their impact on emotions on an aggregated level. Subsequently, it investigates how emotions evolved during the progression of the shopping experiment and whether there are differences in emotions during start, mid and end phase of shopping.

Emotional States on an Aggregated Level

Firstly, effects of the locomotion technique on the three investigated emotions on an aggregated level are discussed. As seen in Table 6 means between the IT and the PW group are found to be fairly similar. Conducting a Welch-Satterthwaite t-test confirmed that there was no statistically significant difference between group means of the two locomotion groups. It is hence suggested that at an aggregated level, a change in locomotion technique did not affect participants' emotional states of engagement, excitement and stress during the virtual shopping experiment. Recent studies imply that bodily states, through proprioception, have a strong effect on affective states (Shafir, 2015). They further showed that specifically adding body movement to a control interface enhances a player's engagement with a computer game (Bianchi-Berthouze, Kim, & Patel, 2007), which is in a sense comparable to a simulated store environment.

Table 6: Comparison of aggregated emotional states between locomotion groups

	Instant Teleportation					Physical Walking						
	N	Min	Max	**Mean**	Std. Deviation	N	Min	Max	**Mean**	Std. Deviation	*F*	*p*
Excitement	33	0.08	0.72	**0.38**	0.18	31	0.08	0.75	**0.38**	0.19	0.000	0.987
Engagement	30	0.43	0.78	**0.66**	0.08	30	0.55	0.87	**0.67**	0.08	0.891	0.349
Stress	30	0.34	0.96	**0.72**	0.19	29	0.33	0.98	**0.71**	0.14	0.128	0.722

*Emotional levels as a scaled value between 0 and 1. **Welch-Satterthwaite t-test, $p < .05$.

However, we could not find any such effects during our shopping experiment for the three measured emotional states. Neither levels of engagement, nor excitement or stress differed between the two investigated locomotion techniques on an aggregated level. This finding indicates that solely adding the act of walking does not impact emotional states for the three investigated emotions in the context of immersive virtual shopping. It is hence suggested that other acts of movement might be more important, for instance standing in front of the shelf, reaching out with one's arm to grasp a product and bending down to inspect products on lower shelf boards. Accordingly, it is concluded that the IT technique is a viable alternative to PW techniques when it comes to shopper emotions.

Variation of Emotional States within the Shopping Trip

Next, it was investigated whether any differences in emotions between the two locomotion techniques in three different shopping phases (start, mid, and end phase) can be detected. As shown in Figure 17, at first glance the emotional levels for engagement, excitement and stress showed fairly similar patterns when comparing the two locomotion methods. The main indication is that in both locomotion groups participants did not experience any strong variation in emotional levels across the three shopping phases. A further series of Welch-Sattertwaithe t-tests was conducted to compare means between the two locomotion groups and found that there was no significant difference in any of the stages (see Appendix H). This indicates that there was no impact of locomotion technique on the three emotions on a more granular level.

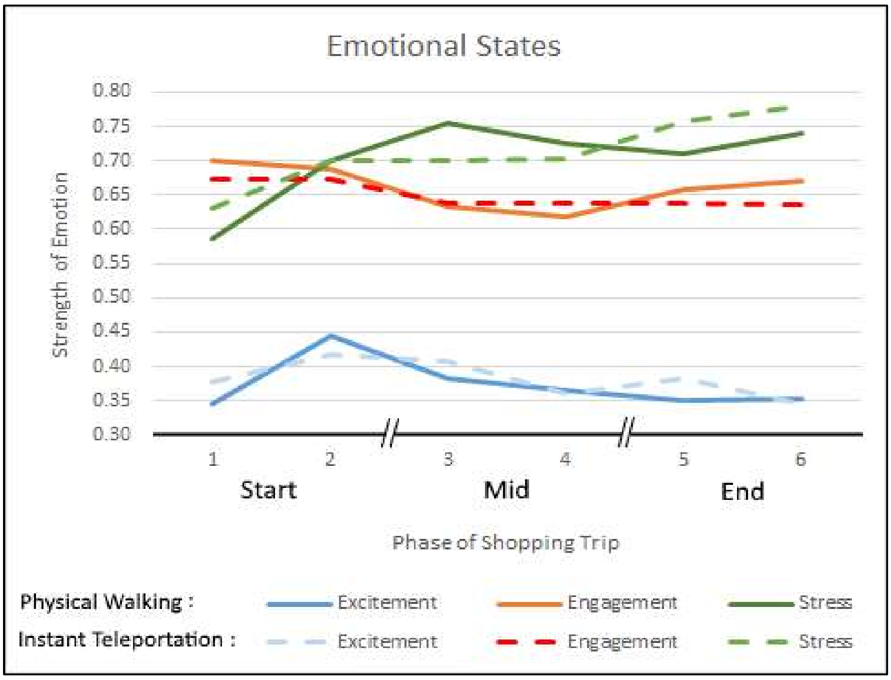

Figure 17: Average emotional strength in three shopping phases

Effects of Locomotion on Shopper Behavioural Metrics

Basket Size, Amount Spent ($NZ), Trip Duration

Further analysis was undertaken to look for differences in the amount of purchases and the time spent for shopping between the two treatment groups. As shown in Table 7, the results only indicate slight differences between the two locomotion techniques. Participants in the PW group purchased slightly more items and spent slightly more money, while the IT group spent slightly more time for their shopping. However, the Welch-Satterthwaite *t*-test did not find any significant differences between group means. These results indicate that the locomotion method had no significant impact on basket size, amount spent and trip duration.

Private Label Share

It was further compared whether the navigation method had a potential impact on private label purchases in the crackers category (the only product category examined due to insufficient purchase rates in the categories). Results show that participants in the PW group purchased 10.3% from a private label brand, while the IT group purchased 12.9% from a private label. However, a Fisher's Exact test did not indicate that the difference is

Table 7: Comparison of shopping behavioural metrics

	Instant Teleportation					Physical Walking						
	N	Min	Max	**Mean**	Std. Dev.	N	Min	Max	**Mean**	Std. Dev.	*F*	*p*
Basket size	36	3	15	**7.14**	2.80	34	4	17	**7.47**	2.91	0.236	0.629
Amount Spent	36	9.49	68.20	**28.79**	13.26	34	12.47	85.91	**29.47**	15.55	0.039	0.844
Trip Duration	36	127.70	836.99	**287.76**	126.87	34	146.14	520.46	**276.83**	112.45	0.146	0.704

*Welch-Satterthwaite t-test, $p < .05$.

statistically significant, χ^2 (1, N = 180) = 0.29, $p = 0.59$, suggesting that the locomotion method had no impact on the magnitude of private label purchases in this product category.

Purchases of Unfamiliar Products

To test whether participants' willingness to purchase unfamiliar products was affected by the locomotion method, one fictional product in each of four different product categories (Ice cream, crackers, fermented tea drink, flavoured milk) was included and purchase frequencies analysed. It was found that only in the crackers category subjects made a sufficient number of purchases to conduct an analysis. Further analysis of this category showed that subjects in the PW group purchased 5.7% of all purchased products from the unfamiliar brand while the IT group purchased half the share, namely 3.2%. However, a Chi-square test did not indicate any significant difference between those two proportions, χ^2 (1, N = 180) = 0.67, $p = 0.41$. This finding suggests that there was no impact on purchases of unfamiliar products caused by the locomotion method.

Amount of Unplanned Purchases

Further analysis tried to determine whether the occurence of unplanned purchases differed between the two locomotion techniques. First, the percentage of purchases from product categories that were not suggested by the task instructions (unplanned purchases) were calculated for each participant. This helped to determine an overall average percentage for each locomotion group. We found that on average, 39.8% of products purchased by participants in the PW group were not from the suggested product categories, compared with a slightly higher number (44.8%) of unplanned purchases made by the IT group. However, further analysis comparing purchase frequencies using a Chi-square test showed that there was no significant difference in the count of unplanned purchases between the two groups, $\chi^2 (1, N = 705) = 0.90, p = 0.34$.

Product Handling Times

Analysis of product handling time across product categories found that the average time that a product was handled was fairly similar with 4.05 seconds (SD = 4.93) in the PW condition compared to 3.97 seconds (SD = 4.39) in the IT condition. The Welch-Satterthwaite *t*-test confirmed that there was no significant difference in means between the two tested samples, $F(1, 693) = 0.01, p = 0.94$.

Store Movement Patterns

Tracking the position of subjects allowed us to visualise movement patterns inside the virtual store and to create heat maps that indicate average in-store dwell time. These heat maps were used to compare in-store movement patterns between the two locomotion groups. Red areas had the highest average dwell time, while blue areas had the lowest average dwell time. The generated heatmap for the current data set suggests significant differences in dwell time patterns that occured between the two investigated locomotion techniques (see Figure 18).

The first observation that was made refers to the bottom aisle in front of the chocolate block category (8). While the data indicated a cloud stretching across the whole shelf in the PW condition, the cloud in the IT condition was more compact and concentrated around the centre of the aisle. This suggests that subjects using the IT method tended to teleport straight to the centre of the aisle to view the shelf facing and skipped surrounding shelf space. In contrast, the PW group was able to stop and inspect products ‘on the go‘, encouraging closer inspection of products that were placed between the centre and the ends of the aisle.

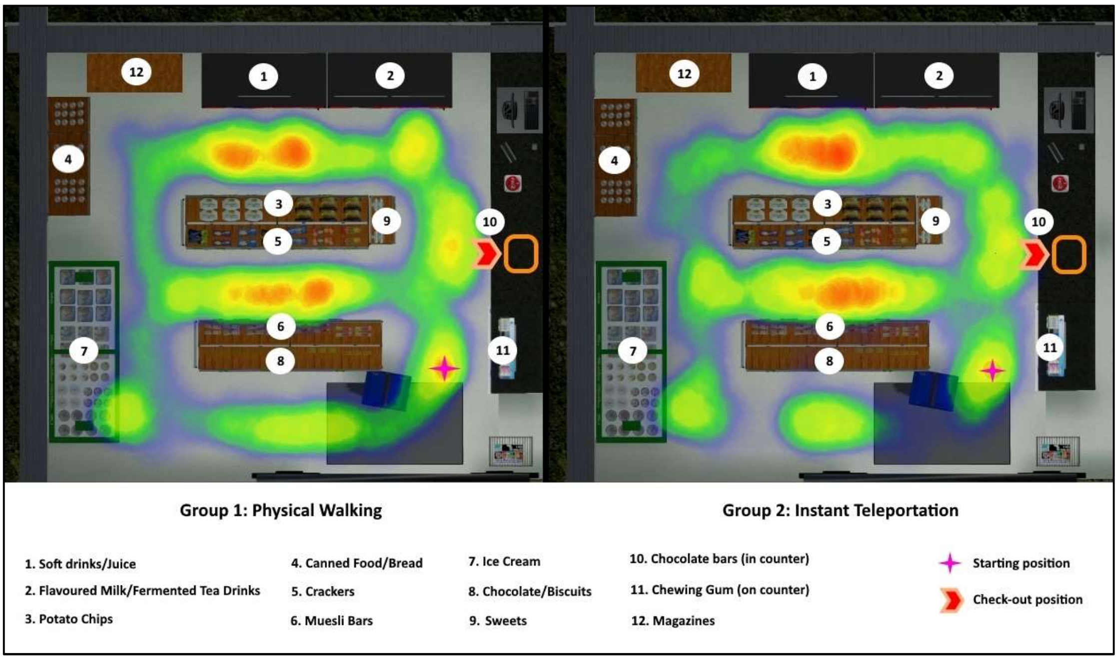

Figure 18: Heat map displaying average shopper dwell time inside the virtual store

Coming to the other two horizontal aisles, in general average dwell time tended to be longer here compared to elsewhere in-store, as these aisles accomodated the two product categories that were suggested by the shopping task. Accordingly, every participant spent time in these product locations. For the middle aisle (in front of crackers category (5)), the IT group had the highest dwell time concentrated around the centre of the aisle, indicated by a more compact red cloud, while the red cloud in the PW group is slightly more spread out and partitioned. In the top aisle, the highest average dwell time was found to be in front of the fridge containing the soft drinks (1). Interestingly, in the PW group participants tended to gravitate around the ends of the fridge (closer to the door handles), while the IT group seemed to have spent an equal amount of time in front of the centre of the fridge. This is in line with our personal observations during the experiment, as we saw that participants in the IT group tended to teleport to the centre of the fridge to inspect the fridge content and then incoveniently bent over to reach the handles to open the fridge doors. They did this to avoid small teleportation jumps.

Further observations highlighted differences in orientation points at the left end of the middle aisle. Participants in the PW group stopped briefly at the end of the aisle for reorientation, while the IT group teleported further into the vertical aisle to maximise visibility of other aisles. Teleporters supposedly did that in order to reduce the number of required teleportation steps for reaching the next product category, while walkers could reorientate and navigate ‘on the move‘. This phenomenon again potentially increases the likelihood of skipping shelf space for teleporters.

The last finding was a phenomon that was observed in both locomotion groups and concerned the chest freezer in the left bottom corner of the store. As seen in the heat map in Figure 18**,** both groups show a tendency to approach the left side of the chest freezer. This avoidance of the right hand side accordingly led to fewer product contacts compared to the left compartment of the freezer. This is illustrated in Figure 19 which shows individual product contacts for the whole sample as green dots. This suggests that shoppers seem to gravitate towards open aisle space when selecting products, a phenomenon that has been described in the retailing literature as the butt-brush effect (Ebster, 2011; Underhill, 2009). These results give first evidence that store movement

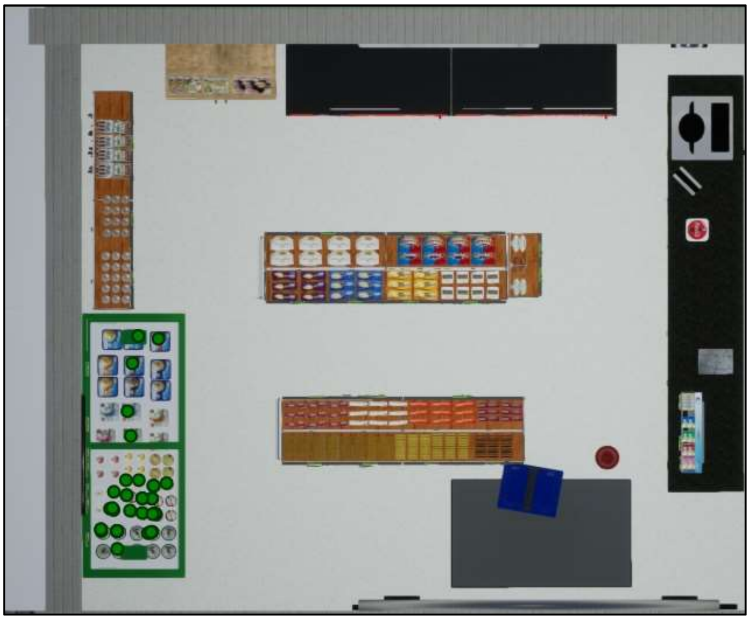

Figure 19: Product contacts in chest freezer unit

patterns in immersive VSS experiments differ depending on the chosen locomotion technique. The aggregated heatmap showed a distinct movement pattern for subjects in the IT group indicating that they gravitated closer to the centre of an aisle. They also made larger jumps from one position to the other and accordingly skipped shelf space and spent more time at aisle intersections for orientation and localisation of new points-of-interest.

In contrast, the PW group used aisle space more evenly and seem to move closer to products rather than operating from a central location. This is more clearly depicted by two exemplatory individual heatmaps we generated for Participants 19 and 44 (see Appendix I).

However, despite observed differences in in-store movement patterns the study did not find an observable difference in the overall number of unplanned purchases between the two groups in this experiment, indicating that impulse purchases were not affected. Nevertheless, more research should look into effects in larger store formats with longer aisles, as skipping shelf space could become more relevant in such a setting.

In summary the reported observations suggest eight key findings:

1. Participants overall felt highly engaged with the VSS shopping task, likely due to immersive elements inside the VSS environment.
2. Participants overall experienced relatively low levels of excitement, likely due to the mundanesness of the grocery shopping context and minor impact of VR technology induced excitement.
3. Stress levels were overall comparatively high, possibly due to the imposed shopping task used for the experiment and the cognitive effort for learning how to use controllers for in-store interaction. Stress levels show steadily increased during the start and end shopping phases, while being stable during the midphase.
4. Excitement peaked at the late start phase (40 seconds into the shopping trip) and kept declining for the rest of the shopping trip.
5. The locomotion technique did not result in changes in engagement, excitement, or stress, either at the aggregated level or in specific shopping phases.
6. The locomotion technique had no impact on basket size, amount spent, trip duration, private labels shares, the probability of purchasing unfamiliar products, the number of unplanned purchases, and the product handling times.
7. The locomotion technique had an impact on store movement patterns. Specifically, the IT technique made shoppers potentially skip shelfspace between the centre and end of an aisle. Moreover, participants that teleported tended to stay in larger spaces when approaching store fitout such as the chest freezer.

4.4 Practical Implications

This research has important implications regarding practitioners' use of immersive 3D store environments for experimental in-store shopper research. The findings are specifically important if developers are forced to resort to a simple locomotion method, such as IT or other controller-supported techniques, out of practicality, budget contraints or space constraints. For instance, using the PW technique requires a tracking area with a clear space of the same size as the virtual store area, such as utilising an empty warehouse or a similarly large building. Besides the costs for providing such a large space, a more advanced tracking solution will be required due to technological limitations of available consumer-grade VR equipment. Hence, researchers will have to apply more cost-effective locomotion techniques that simulate movement in a large scale virtual environment while not requiring a participant to actually move in the physical space, such as the tested IT method.

While the embodied cognition literature suggests that the choice of locomotion technique can potentially cause a bias in shopper emotions and behaviour due to the absence of physical walking, the current study found that applying the IT method did not lead to any observable bias in the three examined emotional states or purchase behaviour. This implies that academic and commercial market researchers can use this method for their virtual store experiments without risking the validity of shopper observations, if some limitations are accounted for. For instance, IT leads to store movement patterns with a potential to skip shelf space that is not located at the mid-point of an aisle; that is, items located between the centre of an aisle and orientation points at aisle intersections. This could specifically impact purchases of products that do not stand out on the shelf, thereby failing to attract shoppers' attention from a greater distance (e.g. products using unobstrusive pack design and colours). Also for VSSs in general, marketers should be aware of the potential for shoppers to experience elevated stress due to an imposed shopping task, particularly for new participants who have to familiarise themselves with the controller use.

Next, recommendations are provided for online-retailers who consider using immersive VR environments as an innovative online shopping platform. Firstly, immersive VR provides a platform that highly engages the shopper with the virtual shopping experience. Participants spent time inspecting items, wandering through the aisles and making unplanned purchases. However, as VR technology itself instigated little user excitement in the context of virtual grocery shopping, users that feel highly immersed might forget about using VR gear potentially making contextual factors of the shopping experience far more important. This finding suggests that design is a major factor in creating shopper excitement in a virtual store environment and with VR technology there are virtually no boundaries for creating creative and customised shopping worlds. How about picking your 'fresh produce' from a virtual farm or shopping for shoes in a Star Wars themed store on a virtual space station? It is proposed that this freedom in creativity should be used to create interactive shopping environments that facilitate shopper engagement and excitement. Moreover, as IT has shown to deliver equivalent results to body-tracking based techniques (PW), results of this study give more confidence in the use of controller-based locomotion in VR online-shopping environments.

4.5 Limitations and Future research

This study investigated the impact of the locomotion method on physiological measures of emotions (EEG) and purchase behaviour. While the experiment delivered first insights into the role of shopper locomotion in virtual store environments, this study was subject to a number of limitations.

Firstly, while there was no evidence that the act of walking makes a difference in aggregated EEG measures and purchase behviour, future research could investigate the absence of other aspects of body-movement (e.g. bending down, reaching out to products) on shopper behaviour in an immersive VSS. Particularly interesting would be to compare emotional responses and behaviour in an immersive walk-around store to a condition of complete absence of physical movement (for instance, a desktop-operated system or seated HMD with game-controller use). The research could then evaluate the importance of manual handling of products and whether shoppers' visual perspective is important to their purchase decisions. The latter point seems important since, unlike VR, the majority of desktop-operated store simulations do not account for participants' height differences.

Secondly, further research could use EEG techniques to measure excitement during recreational shopping activities in an immersive VSS store. While excitement levels amongst participants in our study were low, it would be really interesting to see whether physiological excitement reaches higher levels when shopping for recreational product categories such as apparel, make-up, personal electronics or jewellry. This would provide objective evidence about the difference in shopper excitement between task-based and recreational shopping in immersive VR environments.

Thirdly, the authors encourage further research that looks into the role of stress in immersive VSS experiments. Since the results indicate that stress steadily increased throughout both locomotion groups, it would be really interesting to use EEG to investigate the magnitude of added stress caused by technology use by comparing shopper stress levels between a virtual and a physical shopping environment. Future studies could also look into stress levels after repeated use of the VR system and clarify whether the high stress levels observed can be reduced over time. Studies could further test whether perceived stress is lower in the case of recreational shopping compared to grocery shopping or whether imposed shopping lists in experimental shopper research result in higher shopper stress compared to an unguided shopping task.

Fourthly, the experiment was conducted in a very small store format (approximately four by four metres floor size) which did not allow for large deviations in store movement patterns. Future studies could run similar experiments and investigate how IT impacts shopper locomotion in stores with longer aisle sections. It is specifically recommended to investigate purchase frequencies of products that are situated between the centre and the end of an aisle, as these spaces are bigger in stores with longer aisles. A larger store, which contains a wider product assortment, would allow further investigation of purchase behaviour such as brand shares, private label shares, and shares of impulse purchases in other product categories.

Fifthly, the path tracking technology used in this study provides a convenient way to continuously track a shopper's location in the virtual store. This could be used in retailing research to investigate changes in store layout and atmospherics and their impact on shopper flow and store dwell times. This can be combined with modern eye-tracking equipment and gain even deeper understanding of changes in shopper attention and behaviour.

Lastly, other biometric techniques could be used to investigate shoppers' physiological responses to immersive VSS environments. For instance, there are other techniques to assess shoppers' perceived stress, excitement or engagement via measures of skin conductancy (Jacobs et al., 1994), heart rate, or systolic blood pressure (Malkoff, Muldoon, Zeigler, & Manuck, 1993). Moreover, future studies can use modern eye-tracking technology to record changes in shoppers' pupil dilation (Pedrotti et al., 2014), eye-movement and blink rate during the virtual shopping exercise. These can be used as indicators of cognitive processing (Eckstein, Guerra-Carrillo, Singley, & Bunge, 2017) that help with obtaining deeper insights into shopper attention and decision-making in immersive VSS environments.

4.6 Conclusion

This study investigated whether a controller-based 'instant teleportation' technique for locomotion in a virtual simulated store environment is an adequate alternative to techniques that involve physical walking. The results showed that the absence of physical walking in the virtual store experiment did not impact participants' emotions of engagement, excitement or stress. Further, no differences in purchase patterns relating to shopping trip duration, basket size, amount spent, private label share, the number of unplanned purchases or unfamiliar products were found. While dwell time heatmaps showed that shopper movement patterns differed to some extent between the two locomotion techniques, no difference in the proportion of unplanned purchases was detected, indicating that impulse purchase patterns were consistent. It is hence concluded that instant teleportation, as a cost-effective and easy-to-use locomotion technique, does not appear to bias shopper emotions and behaviour in virtual store experiments when compared to more sophisticated motion-tracking based solutions. These results give more confidence in the use of teleportation-based locomotion techniques, unlocking opportunities for marketing research and online-retailing in large-scale virtual shopping environments.

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STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Alexander
Name/title of Primary Supervisor:	Schnack
Name of Research Output and full reference:	
Does the locomotion technique matter in immersive virtual store environments?	
In which Chapter is the Manuscript /Published work:	Chapter 4
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	60
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Conducting literature review, building virtual environment, planning experimental design, data collection and data analysis, writing manuscript first draft, preparing manuscript artwork.	
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Chapter 5: General Conclusions

The following chapter addresses the contributions of the three studies included in this dissertation. It will answer the overarching research question that asks whether immersive technologies have potential to provide highly authentic VSS environments. This is done by discussing the three specific key aims, summarising derived managerial implications and elaborating on limitations of the dissertation. At the end, the chapter will conclude with suggesting potential directions for future research.

5.1 Main Outcomes

How do immersive walk-around VSS environments compare to desktop-operated VSSs with regards to users' perceived telepresence and system usability?

The two conducted virtual store experiments (chapter 2) that compared telepresence and usability between desktop-operated and immersive VSS found that the immersive VSS system was superior in both aspects. The immersive VSS system was perceived as easier to use regarding store navigation, in the ability to find products in the store and it was in general easier to understand how to use the application. Moreover, participants felt that interactions with the store environment were more natural, visual aspects were more effective and that providing ambient noise supported their perceived immersion. The immersive VR controller interface further interfered less with the performance with assigned tasks compared to the mouse and keyboard interface that was used for the desktop-operated system. These factors increased users' perceived telepresence which potentially leads to more authentic shopper behaviour in VSS experiments compared to systems that use technology that generates lower telepresence (Waterlander et al., 2015). It is hence suggested that immersive walk-around VSS systems in theory lead to shopper behaviour in virtual store experiments that more closely aligns with how individuals naturally behave in a real-world shopping situation than comparative desktop-operated VSS systems.

Are observed behavioural patterns in an immersive walk-around VSS shopping experiment congruent with existing knowledge from the marketing literature?

After study one found that the use of immersive VR technology theoretically leads to more authentic shopper behaviour in VSS environments, the second study in this dissertation (chapter 3) looked at and describes observations of shopper behaviour in an immersive walk-around VSS. An immersive virtual shopping experiment was conducted to investigate shopping metrics that have been shown to be of high relevance in contemporary marketing practices. These observations were then compared to behavioural patterns that were reported in the established marketing literature.

The results showed that shoppers purchased a plausible amount of private label branded products, purchased more private label products in product categories with lower consumption pleasure, preferred to purchase from higher shelf locations, made a plausible amount of impulse purchases and inspected unfamiliar products longer than familiar ones. The study further found some differences in purchase behaviour between males and females.

All the described observations were found to be in line with shopper behavioural patterns that were reported in the marketing literature. Thus, the findings overall conclude that realistic shopping patterns can be expected in immersive walk-around VSS environments and that further research and development into VSSs using immersive VR technology seems justified.

Does controller-based avatar locomotion, in absence of physical walking, in an immersive VSS impact and thus potentially bias shopper emotions and behaviour?

After the two first studies gave more confidence in the use of immersive walk-around VSS for shopper behaviour research, the third study (chapter 4) was designed to investigate the importance of physical walking in an immersive VSS environment. This study was designed to show whether prior validation of shopper behaviour in immersive walk-around store environments can potentially be extended to other locomotion techniques.

An immersive VSS shopping experiment was conducted to test whether shopper emotions and behaviour will change when products are not approached by physical walking. The research compared two popular locomotion techniques for avatar movement in immersive VR environments, namely movement via body-tracking, that involves physical walking, and the controller-based instant teleportation technique.

Results only found minor differences between both locomotion techniques regarding aroused shopper emotions of engagement, excitement and stress. Moreover, investigated in-store metrics such as shopping time, basket size, money spent, private label shares and market shares of unfamiliar products were similar. Only store movement patterns were found to differ between both techniques, with participants in the teleportation group tending to inspect shelf facings more from the centre of the aisle and skipping shelf space between aisle intersections and aisle centres. However, there was no evidence that this impacted impulse purchases.

This study hence concludes that the absence of physical walking does not impact shopper emotions and resulting purchase behaviour. This finding gives more confidence in the widespread use of controller-based avatar movement, that does not involve physical walking, for shopper experiments in immersive VR store environments.

5.2 Managerial Implications

The findings of this dissertation provide significant implications for the development and operation of simulated store environments in market research. The main implication of this research is that immersive walk-around VSS systems are preferable, if stronger perceived telepresence and higher usability are desired in virtual store experiments. Participants' verbatim comments frequently highlighted the high perceived realism of the virtual store environment and that they behaved like in an actual purchase situation. This was further confirmed by findings of the second study that suggest that marketers can expect to find realistic shopper behaviour in immersive VSS environments. Interestingly, the findings support the existence of impulse purchases, a very important aspect of in-store shopper research, despite the fact that participants could not consume real products. The study hence gives more confidence in the use of immersive VSS environments in experimental market research, highlighting its attractiveness as an alternative to traditional survey research.

As for the development of immersive VSSs, the findings provide clear recommendations for the design of avatar movement in the virtual store environment. While locomotion via motion-tracked physical walking seems the more naturalistic and intuitive method, controller-based teleportation delivered an almost identical performance with regards to shopper emotions and purchase decisions. Observed differences in store movement patterns did not indicate any differences in the number of impulse purchases. Marketers are hence advised to use controller-based locomotion via teleportation as this method is not only cheaper but also allows movement through large store formats without requiring a large physical tracking area. This will further enable adoption of immersive VR systems as an online-shopping channel, as tracking-space for VR setups in private households will be limited.

During immersive VR experiments market researchers are advised to allow a generous training and familiarisation session for potential participants as this is vital for a successful immersive VR experiment. Metrics like shopping time and store navigation can be impacted by how proficient participants are with the locomotion technique and store interaction schemes. It is thus important to bring all participants to the same level. It is further advised to control for participants' previous VR experience or 'VR proficiency', if shopping time related metrics are under investigation.

The researcher also should carefully consider the technical specifications of the used hardware and whether the equipment fits the diverse needs of participants. For instance, some VR headsets are not suited for people with bulky hair or large spectacles. Current VR simulations that use locomotion via motion-tracking are not designed to cater for people that require a wheelchair, as simultaneous moving of the wheelchair and using the hand-held controllers is not possible for them. New technical solutions need to be developed for this special user group, if motion-tracked locomotion is to be used. Furthermore, researchers should aim to use HMDs that does not require a wired connection to the computer, as the tangling cable on the back of the headset has been perceived as a negative disturbance by some participants, which can lead to a reduction in immersion and telepresence.

5.3 Limitations and Future Research

While providing exclusive insights into the potential of immersive VSS environments for virtual in-store shopper research, the studies in this dissertation have a number of limitations that will be discussed next.

Firstly, the first two studies did not collect any data about participants' prior immersive VR experience, albeit this factor can have a crucial impact on shoppers' ability to use the VR hardware. There are concerns that this could potentially affect shopping metrics such as product inspection time or total in-store dwell time. For example, participants that, despite the provided training and familiarisation session, struggle with product handling could cause an overestimation of observed handling times. This would not matter for a traditional between-groups comparison, as randomisation would evenly distribute biased individuals over both groups and group differences could still be reliably detected. However, exploratory research that attempts to compare observed shopping metrics to other data sources might lose some validity in this respect. It was hence decided to control for prior VR experience in the third study for this dissertation. Future research could investigate how prior immersive VR experience, or overall tech savviness, impacts shopper behaviour in immersive VR store environments and could provide controlled comparisons to equivalent behaviour in a real-world store.

Secondly, telepresence, one of the key concepts that determine a user's sense of 'being' in an environment, was measured using an adapted form of Witmer and Singer (1998) telepresence questionnaire in order to examine how well the developed software performed with regards to the underlying factors mediating telepresence. Specifically, the questionnaire items are designed to evaluate a diverse set of technical factors that relate to soft- and hardware specifications mediating telepresence. An example is the item "The interactions with the environment seemed natural", with the underlying assumption that perceived naturalness of the environment increases a user's experienced telepresence. Witmer and Singer's original questionnaire contains 32 items. However, only a selected range totalling six items was used for the current research due to concerns that using all 32 original items on top of other survey questions, such as demographics and prior VR experience, could lead to respondent fatigue and data loss caused by participants skipping through questions. Hence, future studies that do not require evaluation of mediating technical factors in the context of telepresence are advised to instead use the presence questionnaire developed by Slater et al. (1994), as this has shown to be a more straightforward method to measure telepresence. This type of questionnaire directly asks participants to indicate the sense of being in an environment and achieves this with only six items. Alternatively, in contrast to discussed subjective measures, a more sophisticated way to measure telepresence is to track actual physiological reactions to trigger events in the virtual environment (Slater & Wilbur, 1997). This method could be explored by further research in immersive virtual store environments given that trigger events do not alter participant behaviour in an undesired manner (Riley et al., 2004).

Thirdly, study two provided a very insightful perspective into shopper behaviour in immersive virtual simulated store environments. However, comparisons with other data sources only give a very rough picture of shopper decision-making in an artificial store environment. This dissertation hence encourages further research into the validity of immersive VSS by designing controlled experiments that investigate purchase metrics and other forms of in-store behaviour and compare those between a real-world store and an identical immersive VR simulation. This research would give an accurate estimation of how much real-world behaviour overlaps with observations in virtual store experiments.

These experiments could then be expanded beyond the convenience store format that was used in this dissertation. Other studies should use larger store formats to enable detailed investigation of shopper flow and look, for instance how crowds, signage or promotion displays steer shopper movement. Accommodating more product categories would allow further investigation of cross-category purchases with emphasis on the occurrence of impulse purchases.

It is encouraged to further the naturalism of controller interface to increase telepresence and usability. In recent years hand-tracking technologies were developed to allow the user to use their own hands for interaction in virtual environments. This tracking was done either per data gloves that carried motion sensors or per finger-tracking using advanced camera systems. It is believed that these systems, that will make controllers obsolete, will significantly further the realism of behaviour in VSSs and introduce another step into the direction of a realistic shopping experience. This could be combined with multi-user VR store applications that will include avatars of other shoppers to simulate social interactions in virtual store environments. In this setup researchers may wish to include eye-tracking cameras in the HMDs to get more detailed insights into eye-movement and identify hot spots of interest in the VR store. Eye-tracking can further be used to detect micro-eye movements, an indicator of perceived stress. This is one of a multitude of physiological indicators of emotional states. Other examples are the measurement of heartrate, skin conductance, blood-pressure, or electric signals emitted by the brain measured via electroencephalography (EEG). All these examples highlight the great potential of immersive VR store environments as a platform for virtual shopper research. A virtual platform that will help the modern marketer to get a better understanding about shopper behaviour in physical retail environments.

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Appendices

Appendix A: Technical Specifications for study 1

	Desktop System	iVR System
Display	Full HD LCD Monitor (24”)	Stereoscopic Head-Mounted Display (HMD)
Screen Resolution	1920x1080 px	2160x1200 px (1080x1200 px per eye)
Input Devices	Mouse & Keyboard	Hand-held Controllers
Movement	Arrow keys (Keyboard)	Body-tracking
Product Rotation	Moving Mouse	Touching touchpad (left side)
Magnification	Not available	Touching touchpad (right-side)
Sound	Only fridge compressor	Fridge sounds, sales clerk, traffic outside, dropping products, sliding fridge doors
Sales Clerk	Stationary, slight movements	Mobile, moving around
Outside Area	Not populated	Passing cars and pedestrians
Aisle Signage	Not available	Available

Appendix B: Sample characteristics for study 1

	Desktop (n=49)	iVR (n=62)	Total Sample (n=111)
	N	N	N
Gender			
Male	16	25	41
Female	33	37	70
Age			
<20	2	0	2
20-29	18	33	51
30-39	12	17	29
40-49	6	6	12
50-59	8	5	13
>59	3	1	4
Education			
School qualification	2	2	4
Certificate or diploma	6	7	13
Bachelor's degree	11	20	31
Postgraduate or higher qualification	30	33	63
Computer Gaming in past 6 months			
Yes	16	25	41
No	29	37	66

Appendix C: Sample characteristics for study 2

Demographic profile	N	%
Gender		
Male	82	53.6
Female	71	46.4
Age		
<20	16	10.5
20-29	57	37.3
30-39	36	23.5
40-49	21	13.7
50-59	14	9.2
>59	9	5.9
Education		
School qualification	22	19.5
Certificate or diploma	27	23.9
Bachelor's degree	15	13.3
Postgraduate or higher qualification	49	43.4
Household yearly income (NZ$) (n=150)		
Less than 10,000	13	8.7
10,001-20,000	11	7.3
20,001-40,000	24	16
40,001-60,000	29	19.3
60,001-80,000	18	12
80,001-100,000	16	10.7
100,001-120,000	12	8
120,001-140,000	7	4.7
Over 140,000	20	13.3

Appendix D: Selected feedback during post-experimental interviews in study 2

It felt quite life like, I enjoyed being able to physically experience walking around a store and view all the items laid out on the shelves.

It felt pretty real. Pretty much forgot that I was inside a room with obstacles.

It felt quite real and felt like I was meant to be in a rush considering Four Square [New Zealand Convenience Store] is a place that I would only shop at when time is limited. Usually I would go to a supermarket.

I was surprised how comfortable I became in the simulator. I became less aware of my actual surroundings while in the store. Surrounding music and effects like the chill of the freezer and fridge would make it more realistic, and [feeling] weight in the basket.

The products were amazing, very realistic. The store was very clear, to proportion and straight-forward to navigate.

Immersion and excitement. And then acceptance and back into my usual buying habits.

Felt strange but became better, started to feel like a real experience.

It was very real, with the actions of purchasing just like normal.

It was very close to reality, regarding the sounds and lights around [Inside the virtual store].

The layout of the shop was clear and easy to navigate, and the prices were all clearly visible.

It felt fairly similar to a real shopping experience.

I really enjoyed the experience and felt like I do when I do shopping for my own parties.

Appendix E: Task description for study 2

Experimental task

Please imagine that it is Friday night. You just came back home from work when you receive an unexpected call from your friends/family inviting you for a social gathering tonight. You gladly accept the invitation and are looking forward to seeing them after a long time. During the call, they ask you whether you could possibly bring some crackers and soft drinks for them and any other snacks you feel like having tonight. With your host's wish in your mind you are putting on your jacket and are jumping in your car. On the way to their house you are pondering where best to buy the required items for the night. As you are already running late and the nearby supermarket is extremely busy at this time of the week, you decide to briefly stop by a local convenience store on the way to your friends'/family's place. Arrived at the store you grab the shopping basket and start your shopping.

Please purchase some crackers and soft drinks as asked by your friends/family. The items should be enough for 4 people. Also, feel free to purchase any other items you feel like enjoying yourself tonight.

Appendix F: Demographic profile of subsamples for study 3

		Physical Walking		**Instant Teleportation**	
		M	***F***	***M***	***F***
Gender		18	17	20	16
		Min	***Max***	***Min***	***Max***
Age (years)		24	65	19	67
		Average		***Average***	
		36.77		36.92	
		N	***%***	***N***	***%***
Education	School qualification	2	5.6	2	5.7
	Certificate or Diploma	2	5.6	1	2.9
	Bachelor's Degree	10	28.6	11	30.6
	Postgraduate or higher	22	62.9	21	58.3
Income	Less than $10,000	3	9.1	1	3.4
	$ 10,001 - $ 20,000	0	0	2	6.9
	$ 20,001 - $ 40,000	5	15.2	5	17.2
	$ 40,001 - $ 60,000	8	24.2	1	3.5
	$ 60,001 - $ 80,000	6	18.2	8	27.6
	$ 80,001 - $ 100,000	6	18.2	5	17.2
	$ 100,001 - $ 120,000	2	6.1	1	3.5
	$ 120,001 - $ 140,000	2	6.1	5	17.2
	More than $ 140,000	1	3	1	3.5
Prior VR experience		14	40	17	47.2

Appendix G – Example data output table for study 3

Part. ID	Group	Basket size	Money spent ($)	Shopping time (s)	Product ID	Price ($NZ)	Shelf number	Inspection time (sec)	Purchased	Brand	Product Category	Private Label	Unique ID
2	1	4	13.48	226.724	129	4.30	4	3.553	0	2	8	0	9
	1				130	2.70	4	2.29	0	2	8	0	16
	1				118	4.30	4	3.385	0	66	8	0	26
	1				123	4.99	3	1.742	0	46	8	0	36
	1				123	4.99	3	2.414	0	46	8	0	36
	1				122	4.99	3	10.355	1	46	8	0	52
	1				144	2.99	5	3.776	0	45	8	0	66
	1				124	3.20	2	1.027	1	19	8	1	86
	1				62	2.80	1	3.631	1	44	1	0	96
	1				82	2.49	1	0.749	0	33	5	0	107
	1				82	2.49	1	1.096	1	33	5	0	107
3	2	7	19.76	314.636	127	3.60	2	1.899	1	69	8	0	16
	2				126	3.60	2	1.386	1	69	8	0	27
	2				123	4.99	3	0.971	0	46	8	0	10
	2				120	1.90	4	1.475	1	67	8	0	61
	2				0	3.89	3	1.408	1	13	0	0	63
	2				67	3.89	3	1.911	1	27	0	0	69
	2				73	1.99	3	1.475	1	31	0	0	72
	2				168	4.09	4	15.682	0	54	3	0	91
	2				24	4.49	3	1.274	1	56	9	0	138

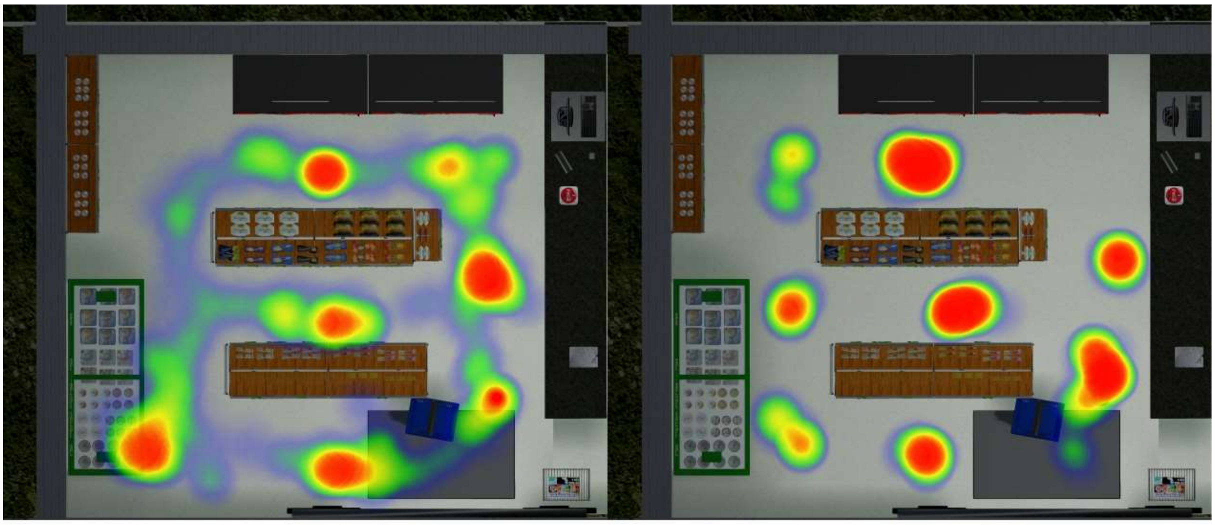
* For dichotomous variables: 0 = No, 1 = Yes

Appendix H – Average emotional levels in different shopping phases in study 3

		Physical Walking		Instant Teleportation			
		N	Mean	N	Mean	**Welch**	***p***
Engagement	Start 1	30	0.70	30	0.67	1.007	**0.320**
	Start 2	30	0.69	30	0.67	0.502	**0.482**
	Mid 1	30	0.64	30	0.64	0.023	**0.879**
	Mid2	30	0.62	30	0.64	0.277	**0.601**
	End 1	30	0.66	30	0.64	0.851	**0.360**
	End 2	30	0.67	30	0.64	1.936	**0.169**
Excitement	Start 1	31	0.35	33	0.38	0.462	**0.499**
	Start 2	31	0.45	33	0.42	0.175	**0.677**
	Mid 1	31	0.39	33	0.40	0.149	**0.701**
	Mid2	31	0.37	33	0.36	0.003	**0.954**
	End 1	31	0.35	33	0.38	0.235	**0.630**
	End 2	31	0.35	33	0.35	0.022	**0.883**
Stress	Start 1	28	0.59	29	0.63	0.876	**0.353**
	Start 2	28	0.70	29	0.70	0.001	**0.978**
	Mid 1	28	0.75	29	0.70	1.191	**0.280**
	Mid2	28	0.73	29	0.70	0.162	**0.688**
	End 1	28	0.71	29	0.76	0.669	**0.417**
	End 2	28	0.74	29	0.78	0.69	**0.410**

*Emotional levels as a scaled value between 0 and 1. **Welch-Satterthwaite t-test, $p < .05$.

Appendix I – Example individual heat maps for study 3



Subject 44 - Physical Walking   Subject 19 - Instant Teleportation

Appendix J – Brand familiarity questionnaire based on Kent and Allen (1994)

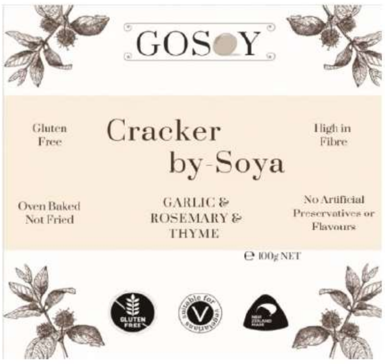
Please enter participant ID

Now we like to know how familiar you were with the following brands. Please indicate your level of familiarity **before you saw them in the experiment.**

	Strongly agree						Strongly disagree
I was familiar with that brand	○	○	○	○	○	○	○
I was experienced with that brand	○	○	○	○	○	○	○
I was knowledgeable about that brand	○	○	○	○	○	○	○

	Strongly agree						Strongly disagree
I was familiar with that brand	○	○	○	○	○	○	○
I was experienced with that brand	○	○	○	○	○	○	○
I was knowledgeable about that brand	○	○	○	○	○	○	○

	Strongly agree						Strongly disagree
I was familiar with that brand	○	○	○	○	○	○	○
I was experienced with that brand	○	○	○	○	○	○	○
I was knowledgeable about that brand	○	○	○	○	○	○	○



	Strongly agree						Strongly disagree
I was familiar with that brand	O	O	O	O	O	O	O
I was experienced with that brand	O	O	O	O	O	O	O
I was knowledgeable about that brand	O	O	O	O	O	O	O

	Strongly agree						Strongly disagree
I was familiar with that brand	O	O	O	O	O	O	O
I was experienced with that brand	O	O	O	O	O	O	O
I was knowledgeable about that brand	O	O	O	O	O	O	O

	Strongly agree						Strongly disagree
I was familiar with that brand	O	O	O	O	O	O	O
I was experienced with that brand	O	O	O	O	O	O	O
I was knowledgeable about that brand	O	O	O	O	O	O	O

	Strongly agree						Strongly disagree
I was familiar with that brand	○	○	○	○	○	○	○
I was experienced with that brand	○	○	○	○	○	○	○
I was knowledgeable about that brand	○	○	○	○	○	○	○

	Strongly agree						Strongly disagree
I was familiar with that brand	○	○	○	○	○	○	○
I was experienced with that brand	○	○	○	○	○	○	○
I was knowledgeable about that brand	○	○	○	○	○	○	○

	Strongly agree						Strongly disagree
I was familiar with that brand	○	○	○	○	○	○	○
I was experienced with that brand	○	○	○	○	○	○	○
I was knowledgeable about that brand	○	○	○	○	○	○	○