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Enhancing Collaborative Shopping Experience Through Interactive Personalized Avatars and Shared Gaze in a Multi-User Augmented Reality Environment

Shihui Xu, Like Wu, Wenjie Liao, and Shigeru Fujimura

Graduate School of Information, Production and Systems, Waseda University, Kitakyushu, Japan

ABSTRACT

Augmented Reality (AR) has been used to enhance the shopping experience. However, existing AR shopping systems mainly focus on the solo user's experience, while lacking multi-user experience. To address the gap, we propose a novel approach to collaborative shopping in a multi-user AR environment. By integrating the interactive personalized avatars of customers and shared gaze cues between shopping companions, we aim to understand how these technologies can enhance the collaborative shopping experience. We recruited thirty participants to conduct a 2 (personalized avatar: static vs. interactive) times 2 (shared gaze: without vs. with) within-subject repeat user study. The quantitative results from questionnaires showed that both interactive personalized avatars and shared gaze cues had positive effects on participants' perceptions of enjoyment, usefulness, communication, co-presence, and future use. The combination of two features further enhanced the communication and perceived co-presence between shoppers and was preferred by participants. The qualitative results showed that interactive personalized avatars and shared gaze cues can enhance the shopping experience and promote efficiency which is consistent with quantitative results.

KEYWORDS

Collaborative shopping; augmented reality; interactive personalized avatar; shared gaze; multi-user augmented reality experience; shopping experience

1. Introduction

With the development of e-commerce, retailers have been exploring new ways to enhance the shopping experience for their customers, and Augmented Reality (AR) or Mixed Reality (MR) has emerged as a promising solution (Porter & Heppelmann, 2017). AR facilitates the elimination of the cost of mentally translating 2D information into a 3D world, bridging the gap between the digital (E-commerce websites) and the physical world simultaneously, and allowing people to perceive product information and make purchase decisions comfortably (Heller et al., 2019; Hilken et al., 2017; Uhm et al., 2022). Users' perceived augmentation leads to the formation of decision comfort in AR shopping experience via a utilitarian and a hedonic path (Ivanov, Head, et al., 2023). However, consumers will find that these systems are often designed for a single user. According to statistics, 90% of consumers like to establish a connection with humans during shopping activities (Goswami et al., 2007), and 70% prefer to shop with pals (Chebat et al., 2014). Therefore, there is a gap between the current AR-based e-commerce system and customer needs. The customer is devoid of the companionship, guidance, and social connection they once enjoyed during in-person shopping.

Collaborative shopping is a shopping activity in which a customer purchases together with others (Zhu et al., 2010). Researchers have made some studies on it (Chebat et al., 2014; Goswami et al., 2007; Huang et al., 2011; Izadi et al., 2021; Wei et al., 2017; Yue et al., 2014; Zhu et al., 2010). Shoppers report higher shopping value and emotional experiences when shopping with friends compared to when shopping alone (Borges et al., 2010). Although there are many benefits to both AR shopping and collaborative shopping, how to use AR technology to enhance the collaborative shopping experience has rarely been studied. To address the gap where users of AR shopping systems are usually isolated and tend to prefer shopping with a companion, we propose a collaborative AR shopping system. Additionally, we aim to enhance the collaborative shopping experience by using interactive personalized avatars and shared gaze between shopping pals. Specifically, our interest lies in understanding the impact of these two factors on users' experience of the collaborative shopping system. Previous studies have identified the effectiveness of personalized avatars in improving embodiment and personalization in the context of e-commerce. However, to the best of our knowledge, the interaction with personalized avatars has not been explored. The effect of shared gaze on collaborative shopping has not been well understood either.

This study aims to investigate the effects of interactivity of personalized avatars and shared gaze on collaborative shopping in a multi-user AR environment. By examining the impact of these two features on shoppers' perceptions and behaviors, we hope to shed light on their potential for

CONTACT Shihui Xu shxu@toki.waseda.jp Graduate School of Information, Production and Systems, Waseda University, Kitakyushu, Fukuoka, Japan

enhancing the collaborative shopping experience. The main contributions of this work are:

- The design and a proof-of-concept prototype implementation of a multi-user AR collaborative shopping system using interactive personalized avatars and shared gazes.
- Quantitative and qualitative evaluation of interactive personalized avatars and shared gazes and their interaction effects on the collaborative shopping experience.
- Discussion and implications for future work to enhance the collaborative shopping experience.

In the following pages, we first provide a brief overview of the relevant literature on collaborative shopping, personalized avatars with interaction, and shared gaze in a collaborative environment. Then we describe our design of an AR-based collaborative shopping framework, including three components: shared AR shopping environment, interactive personalized avatar, and shared gaze. Next, we introduce the implementation details. The next section goes into the evaluation part. Finally, we present our findings and discussion for both theory and practice.

2. Related work

We built this research on collaborative shopping, collaborative AR systems, personalized avatars with interaction, and shared gaze in a collaborative environment.

2.1. Collaborative shopping

Shopping motivations refer to the underlying reasons why individuals engage in shopping. Arnold and Reynolds (2003) suggest that motivations vary individually and are shaped by personal preferences, needs, and societal factors. Some common shopping motivations include functional (utilitarian) motivation, hedonic motivation, social motivation, emotional motivation, self-expression motivation, bargain-hunting motivation, and convenience motivation. These motivations can overlap and vary in importance depending on the individual and the specific shopping context. Additionally, cultural and societal factors can also influence shopping motivations.

Collaborative shopping can be thought of as a form of social shopping, a consumer activity when shopping on an e-commerce site with one or more shopping partners concurrently (H. Kim et al., 2013; Zhu et al., 2010). Social shopping is based on social relationships in which consumers' shopping experiences and purchasing behavior can be influenced by others (Lee et al., 2011). It explicitly benefits consumers in terms of improving decision-making, enhancing the shopping experience, and increasing accountability. Social shopping for apparel involves seeking opinions from others through social networking sites (SNSs) about products and brands before making purchase decisions (J.-Y. M. Kang & Johnson, 2013). Pantano and Gandini (2017) explored the behavior of young consumers in relation to the usage of social network technologies as a substitute for face-to-face interactions while shopping for apparel to understand how they seek advice and suggestions from their friends through social media platforms. Morris et al. (2014) reported that the crowdsourced feedback from social networks provided pertinent comments leading to confident purchase decisions.

J. Kang and Park-Poaps (2011) examine the motivational antecedents and consequences of social shopping for fashion. They found that the antecedents of social shopping for fashion, including apparel, are social comparison orientation, ability comparison, and opinion comparison. The consequences of social shopping for fashion include product satisfaction and experience satisfaction. Social shopping enhances product satisfaction by making information seeking and processing more efficient, and it enhances experience satisfaction by providing positive emotional and arousal compensations such as fun, pleasure, love, friendship, and acceptance. Involving customers in the co-creation process (a form of social collaboration between retailers and customers) not only increases customer satisfaction, but also enables companies to leverage social media and online communities for sharing, promoting, and discussing their co-created products (J.-Y. M. Kang, 2017).

The shopping experience is influenced by the interactions during the customer journey (Esfidani & Izadi, 2023). The social interactions under shopping scenarios can be classified into (1) employee–consumer, (2) consumer–consumer, (3) employee–consumer–consumer, and (4) employee–consumer–third party (key online influencers, bloggers) (Wanick & Bazaki, 2020). Collaborative shopping provides interactions among consumers' social networks, helping them share their opinions and find offers of products (Hilken et al. 2020; H. Kim et al., 2013). Hilken et al. (2020) conducted a series of studies to explore shared decision-making in the marketplace, in which decision maker who purchases products and recommender who gives opinions are "purchase pals." Furthermore, the activities during social shopping, such as sharing social coupons and opinions of products, stimulate consumers' desire for products and positive behavioral intentions due to the sense of social empowerment.

The advantages of social shopping have sparked academic interest in implementing a system that incorporates consumer interactions. For example, Zhu et al. (2010) investigated shared navigation and communication support effectively reduced uncoupling incidents in collaborative online shopping. H. Kim et al. (2013) examined that embodiment and media richness could positively influence shoppers' experience. Wei et al. (2017) compared co-browsing with traditional chat browsing for shopping on an e-commerce website. They found that co-browsing can lead to a more engaged experience compared to the chat-only condition. In the field of computer science, certain prototypes were proposed to improve product selection and increase shopping efficiency, in which users can shop together with other people (von Zadow et al., 2015) or intelligent agents (Alhamdan et al., 2020; Chen et al., 2021). For example, Yue et al. (2014) presented a co-navigation system to support collaboration during online shopping, including a split screen to encourage diverse product search, and a shared view to enable better coordination. Cai et al. (2018) demonstrated ShoppingTogether, a remote co-shopping system, in which one user can shop at the offline store and another user accesses shopping feeling remotely through video-based view-sharing and gestural interaction.

2.2. Collaborative AR systems

Computer Supported Cooperative Work (CSCW) has long been concerned with understanding and designing technologies that support collaboration. AR or MR technology has become an effective and powerful candidate, and many researchers have developed collaboration systems that take advantage of this technology (Ens et al., 2019).

Regarding the definition of AR, Milgram' s Reality-Virtuality Continuum is the classic starting point for explaining the design space (Kuksa & Childs, 2014; Milgram et al., 1995; Milgram & Kishino, 1994). Reality-Virtuality Continuum is a continuous scale ranging from *reality*, which only consists of the physical environment, to *Virtual Reality (VR)*, which only consists of the virtual, computer-generated synthetic environment (Kuksa & Childs, 2014). *Mixed Reality (MR)* is defined as the continuum in-between, including two subsets: *Augmented Reality (AR)* and *Augmented Virtuality (AV)*. AR depicts adding virtual objects into the physical world, which is closer to the end of *reality*. While AV is the part of the MR continuum toward *virtual* end, introducing physical objects into the virtual environment (Ens et al., 2019). Our research primarily explores integrating virtual products, avatars, and other digital objects into the physical environment to build a collaborative shopping system using AR technology. Here we review previous work on how AR can facilitate collaborative work.

In the field of CSCW, two essential elements are needed to support collaborative work: (1) common ground, referring to a state of mutual understanding among participants in a collaborative task, where there is a shared understanding of joint goals, shared resources, and the state of the task-solving process (Gutwin & Greenberg, 2002; Marques et al., 2021); and (2) deixis, which includes context-dependent linguistic features such as pronouns and spatial or temporal adverbs (I, you, here, there, now, hereby, etc.) (Levinson, 2006), is essential for understanding how information facilitates collaboration (Marques et al., 2021) and improving collaborative tasks' efficiency and satisfaction. AR develops common ground by providing collaborators with a shared understanding or a common environment (Marques et al., 2021). AR supports communication cues, such as pointers (Bauer et al., 1999; Greenberg et al., 1996), annotations (Gurevich et al., 2015), hand gestures (Bai et al., 2020; Piumsomboon et al., 2017), and spatial information about objects, events, and areas of interest (Billinghurst & Kato, 2002; Palmarini et al., 2018). These help collaborators align their understanding of the task and the environment, promoting communication and coordination (Marques et al., 2021). Furthermore, AR enables collaborators to overlay responsive computer-generated graphics on top of the physical world environment, allowing for the sharing of contextual data (Azuma, 1997). This shared augmented environment improves alertness, awareness, and understanding of the situation, enabling collaborators to have a common reference that facilitates collaboration (Ens et al., 2019). AR combines language, visual elements, gestural interaction, and tactile feedback to enhance deictic reference. AR can display virtual indicators directly in the user's field of view, such as arrows, frames, and highlight specific objects. These indicators can come from cursors representing where one's focus is, captured user gestures, or the user's gaze. This intuitive visual aid enables participants to quickly and accurately focus on the same thing together, thereby enhancing the deixis expression of the space. For example, during a collaborative design or repair task, one user can point to a specific part of a complex device through an AR interface, and other users can immediately see this indication, even if they are in different locations.

Collaborative shopping can also be seen as a collaborative task, and for it to be an efficient and enjoyable experience, shopping partners need to establish common ground with each other, and technology-assisted deixis is necessary to enable collaborators to understand and apply information. In this research, we use AR technology to create a shared shopping environment, featuring interactive personalized avatars as proxies for shoppers and enabling them to share their gazes. Next, we will review related works concerning interactive personalized avatars and shared gazes, revealing the potential of these factors to improve collaborative shopping.

2.3. Personalized avatars with interaction

An avatar is described as a graphical representation created using computer technology, enabling a user to establish an alternate identity and self-identification within an online environment (Holzwarth et al., 2006; Suh et al., 2011). There have been a lot of previous studies (Hoyet et al., 2016; Jo et al., 2017; Jung & Hughes, 2016; Jung et al., 2018; Lugrin et al., 2015, 2018; Schwind et al., 2017; Waltemate et al., 2018) that explore the effect of personal avatar representation on body connectivity of the self. Latoschik et al. (2017) and Zibrek et al. (2018) found that the realism in the avatar positively enhances its expression in virtual environments. Moreover, the whole body avatar was tested effective in collaboration for improving *co-presence*, the sense of being together in a mediated communication environment (Yoon et al., 2019). Waltemate et al. (2018) compared generic avatars with personalized scanned versions and found that personalized avatars increased presence. Personalized avatars, especially realistic avatars with gestures and expressions (Casanueva & Blake, 2001), contribute to users' perception of presence, which has a positive impact on users' shopping enjoyment and intention to use a collaborative shopping system (Zhu et al., 2006).

However, the effect of personalized avatars on the shopping experience varies from person to person. Typically, personalized avatar generation involves uploading a personal photo to create a virtual representation of themselves. Users' satisfaction with the photos at this stage can significantly influence their perception of the entire shopping system and their intention to use it (Tawira & Ivanov, 2023). Besides, users who value privacy and have the option to use pre-loaded avatars may be more satisfied with the virtual try-on app, while users with higher body esteem may derive more satisfaction from using a personalized avatar (Ivanov, Mou, et al., 2023).

Interactivity is essential for shopping (Esfidani & Izadi, 2023). Previous work (Fiore et al., 2005) examined that Image Interactivity Technology (IIT), referring to the use of advanced technologies, such as virtual model technology, interactive interfaces, and other digital tools, enhanced consumers' overall experience and satisfaction with the online retailer. This is primarily because these technologies enable more vivid product displays and personalized shopping experiences, thereby enhancing consumers' positive attitudes, trust, credibility, and likability. Researchers have employed personalized avatars to create immersive and interactive consumer shopping experiences. For example, Liu et al. (2020) used personalized avatars for virtual try-on applications. Moreover, Manfredi et al. (2023) developed an application that utilizes real-time garment simulation algorithms, a 3D avatar accurately reflecting the customer's body shape, and functionalities including avatar customization and motion tracking. This approach allows consumers to see how clothing looks on a virtual model similar to their own body during the shopping process, significantly enhancing the intuitiveness and engagement of the shopping experience. Although using personalized avatars in shopping systems effectively improves interactivity and the shopping experience, few studies explore the impact of different interactivity of personalized avatars on the shopping experience.

We want to improve the interactivity of the overall shopping experience by improving the interactivity of personalized avatars, thereby improving the user's shopping experience. In this study, an interactive personalized avatar can be defined as a virtual representation of a user that is customized to resemble the user's embodiment and behavior and is designed to interact with the user and with objects in virtual and real environments. Freiwald et al. (2021) show that continuous movement of avatars significantly improves perceived coexistence and fairness in multi-user VR applications. We hope to give personalized avatars this kind of interaction to enhance the overall experience.

2.4. Shared gaze in collaborative environment

Gaze refers to the pattern of eye movement and where a person is looking during social interactions or other tasks (Emery, 2000; Langton et al., 2000). Gaze can contain rich information, including attention (Emery, 2000), cognitive processing (Winsor et al., 2021), emotion (Liang et al., 2021), and intention (Baron-Cohen et al., 1997). Sharing gaze in a collaborative application helps to establish common ground and enable awareness among collaborators, reducing the need to identify shared interests and task progress (Ens et al., 2019). For instance, an early study by Kiyokawa et al. (1999) proposed drawing a line from the center of a collaborator's eyes toward the direction they are looking. This approach aims to augment facial orientation information in shared VR and AR systems. Piumsomboon et al. (2017) introduced COVAR, which was able to share the collaborators' head frustum, head-ray, gaze-ray, and hand gestures to facilitate collaboration between AR and VR users. Piumsomboon et al. (2018) also reported that redirected gaze improved common ground between collaborators

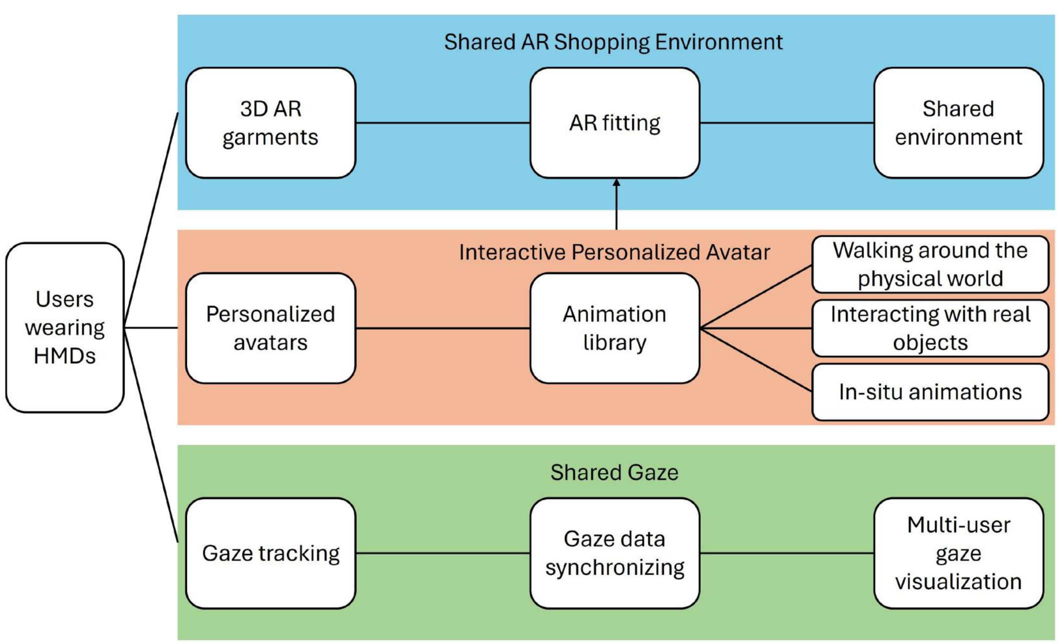

Figure 1. Overall multi-user AR collaborative shopping system architecture with interactive personalized avatars and shared gaze. The arrow from interactive, personalized avatar to AR fitting means that the users can use their own interactive, personalized avatars to try on clothes in AR fitting.

in their collaborative AR system Mini-Me. Zhang et al. (2017) conducted user studies to understand the effects of shared gaze in a co-located collaborative search task. Their results showed that gaze enhanced collaboration and communication, making them aware of their partner's interests and attention. Brennan et al. (2008) investigated the effects of sharing gaze in a remote collaborative search task. They found that sharing gaze information reduced the search time. Bai et al. (2020) conducted a study investigating the combination of sharing eye gaze with hand gestures in a live 3D panorama remote collaboration system. They found the combination of sharing gaze and gesture significantly affected users' perceived sense of co-presence. From the examples above, it can be concluded that sharing gaze data in a collaborative system can help collaborators establish common ground and improve work efficiency, communication, and co-presence. In face-to-face collaboration, deixis is always used in conjunction with eye gaze. The gaze is both a means of perception and communication (Cherubini et al., 2008). Providing shared gaze visualization in collaboration enables the active use of deictic reference, promoting shared focus on interests (Jing et al., 2022).

The consumers' gaze reflects their interest and attention to the product when shopping. Some studies analyze consumers' preferences for products through users' gaze data (Boardman & McCormick, 2023; Huddleston et al., 2018; Nordfält & Ahlbom, 2024). In the shopping scenario, M. Kim et al. (2015) presented a gaze-based interaction concept to enhance in-store shopping with social information. Based on the user's gaze, they projected information onto the product and its surrounding area, including collective in-store gazes and online social comments. Their system allows consumers to interact with items through gaze, thereby enhancing the shopping experience. However, users in their system do not engage in social interaction during shopping through real-time shared gaze. We hope to explore further the effects of sharing gaze in real-time collaborative shopping experiences.

2.5. Summary of related works

In summary, collaborative shopping is necessary to enhance shoppers' practical and hedonic value in the shopping process. However, there are still several issues that need to be resolved. The first is how to design collaborative shopping systems to support current shoppers' needs for shopping together. The second question is how to use AR technology to enhance the collaborative shopping experience. We need to think about what role AR technology can play in collaborative shopping systems and whether AR technology is useful for collaborative shopping experiences. To answer these questions, a new AR-based system dedicated to collaborative shopping is needed.

Previous work suggests that personalized avatars and gaze sharing may have the potential to improve collaborative systems. However, previous research on personalized avatars mostly focused on the appearance and style of avatars. Only a few studies mentioned the interaction of avatars, and they were only simple interactions such as moving and placing avatars. Furthermore, personalized avatars and their interactions have not been studied in collaborative shopping. There has been no research on improving the collaborative shopping experience by enhancing the interactivity of personalized avatars.

The gaze interface has also been proven beneficial for collaborative work in previous work. However, there is no related work on designing and implementing gaze sharing in collaborative shopping scenarios. And the impact of sharing gaze on the collaborative shopping experience has not been revealed.

To solve the above problems, we propose a new AR-based collaborative shopping system that combines a personalized avatar with improved interaction and a multi-person gaze-sharing interface. According to the conceptual model of Wanick and Bazaki (2020), our proposed system focuses on the scenario of consumer-consumer interactions. Our proposal provides more realistic personalized avatars with improved interactivity than previous systems. We also provide a more intuitive and collaborative AR shopping environment by sharing the gaze of users. In this scenario, consumers can contact friends and family to share the AR shopping environment, where both utilitarian and hedonic aspects are significant. Interactions would include advice from other consumers and depend on the level of trust established. Each component of the system will be introduced in detail below.

3. System architecture

3.1. Overview

In this study, we mainly focus on enhancing collaborative shopping for garments. We selected garments for three reasons. First, shopping for garments is a common scenario that happens to almost everyone that can stand for the typical shopping scenario. Second, the garment is an experiential product category that is hard to evaluate, so people tend to rely on evaluations from others. Last, the garment is highly related to the personal ego which can be used to express consumers' personality, carrying visual cues through which consumers are likely engaged in social activities while shopping (Johnson et al., 2014). This attribute of Garment induces us to choose it as a product for studying collaborative shopping.

Our prototype system is an AR-based multi-user collaborative shopping system that is developed based on the proposed architecture (Figure 1). Our system is in a geographically co-located setting and makes use of personalized interactive avatars and shares the mutual gaze of users. The users wear head-mounted displays (HMDs) to join in the collaborative shopping. Compared with previous collaborative shopping systems, it has three new elements:

1. a multi-user shared AR shopping environment, including 3D AR garments, AR fitting, and the synchronization of the whole environment;

Figure 2. Image of shared AR shopping environment.

2. the interactive personalized avatar with three modules, including a personalized avatar that reflects the user's face and body shape, which can be used as a fitting model, an animation library corresponding to the personalized avatar, and three aspects of interaction;
3. a mutually shared gaze interface to facilitate collaboration, including three modules: gaze tracking, gaze data synchronization, and gaze information visualization in multi-user scenarios.

The system architecture will be described in detail. A video link that shows a recording of the main functions of the system is provided.[1]

3.2. Shared AR shopping environment

We built a room-scale AR shopping system, which enables several users to have a shopping experience together, as Figure 2 shows.

3D AR garments are provided for users to intuitively observe the effects of clothing from 360 degrees. To ensure the fidelity of 3D garments, we select clothes from a real shopping website for modeling. Detailed pictures and sizing information are provided for each garment on this site. In this way, we can get the shape, size, and pattern of the clothes. We also made clothing models with different sizes based on the clothing size information on this website.

AR fitting allows users to try on clothes with their own personalized avatars, so users can preview how the clothes will look on themselves. AR fitting allows users to try on multiple pieces of clothing in a short period, improving the efficiency of clothing selection.

A shared environment means that the users share the real physical world and the virtual world. Our target scenario is collaborative shopping in a co-located situation synchronously among a small group size. The co-located situation means the collaborators are in the same physical environment, so the physical world is inherently shared. And in this case, users can communicate through natural communication cues such as voice and body gestures, because they are not isolated from the physical world. For sharing the virtual world, we synchronize the virtual objects and the interactions for each user. The collaborators can interact with the same virtual objects while being aware of the other user's interactions. By doing this, we aim to provide collaborators with independent omnidirectional natural views. This is achieved by calibrating the coordination of different users' AR environments using a printed QRcode placed in the real space. Synchronously denotes that all collaborators have access to the AR system and can interact with it simultaneously while receiving immediate feedback and visual updates from the system. This approach enhances the sense of co-presence and collaborative engagement among users and enables them to achieve common goals in a coordinated manner. Basically, our setup is designed to facilitate usage by a small group, consisting of at least two individuals.

3.3. Interactive personalized avatar

Interactive personalized avatars consist of three modules: creating personalized avatars, building the animation library for personalized avatars, and the runtime interaction of personalized avatars.

3.3.1. Creation of personalized avatars

We adopt the personalized avatar in collaborative shopping to enhance the shopping experience. The personalized avatar can reflect the body shape and appearance of users and is life-sized. The creation of a personalized avatar has three steps. The head of a personalized avatar is generated using the 3D character modeling software, CharacterCreator. By inputting a selfie of a user, CharacterCreator will output a realistic character that can reflect the facial appearance of the user. Secondly, we create the user's 3D body model through Meshcapade Me. By inputting the user's body data,

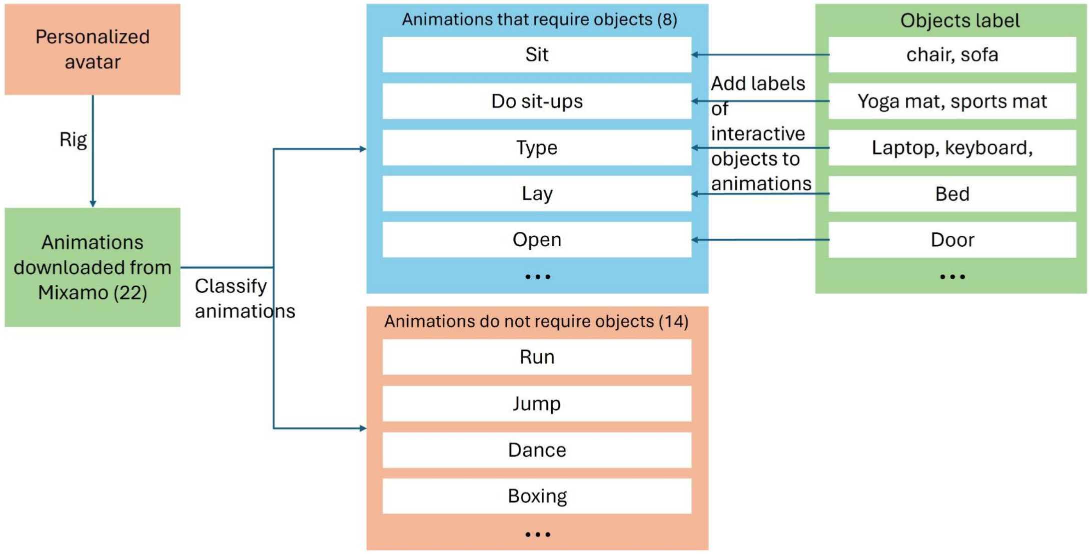

Figure 3. The process of building an animation library for a personalized avatar.

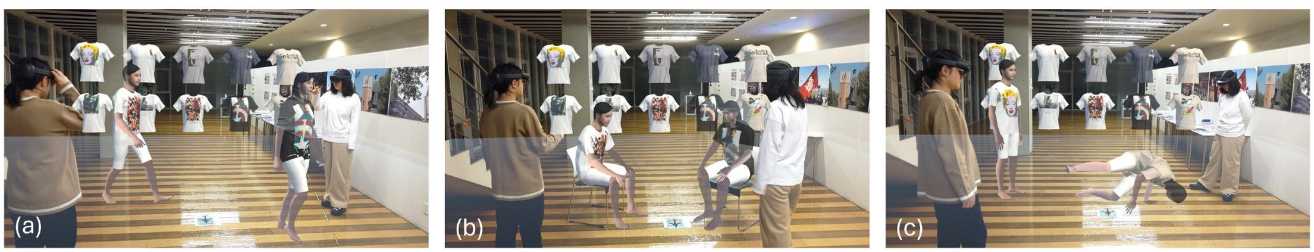

Figure 4. Two users are using three kinds of interactions to experience interactive personalized avatars for collaborative shopping. (a) Walking around the physical world. (b) Interacting with real objects (two users' avatars are sitting on chairs). (c) In-situ animations (one user's avatar is standing and the other user's avatar is dancing).

including height, weight, age, and so on, the user's body shape will be calculated. Finally, we connect the head model and body model using 3D modeling software Blender, so that the created avatar matches the user's body shape and appearance. Previous research has found that the embodiment of users using avatars can enhance shoppers' experience in online shopping (J.-H. Kim et al., 2009; Yoo & Lennon, 2014). And personalization of avatars can improve the co-presence of users in collaboration tasks.

3.3.2. Building animation library

The animation library is established to prepare for the interaction of personalized avatars. Figure 3 shows the process of building an animation library for a personalized avatar. To build the animation library of a personalized avatar, we use Mixamo to rig the personalized avatar and insert animations downloaded from Mixamo. In total, 22 animations are selected for our system. The animations are classified into two categories: animations that require objects to complete actions and animations that can complete actions without objects. For each animation that requires objects, the interactive objects' labels will be added. For example, the sitting animation matches a chair and a sofa, and the typing animation matches a laptop and keyboard. Animations with object labels can be used for the avatar's interaction with real objects.

3.3.3. Interactions

Our system utilizes interactive personalized avatars that can interact with both the real physical world environment and with other users in the virtual environment. Although previous research has presented applications of the interactive avatar in education and cyberpsychology, these avatars are limited to interacting with only humans or the virtual world. To ensure the customer gets a good shopping experience, the quality of interaction during the shopping process is vital, including the interaction with the products and other customers. In this research, the proposed interactive personalized avatar has three kinds of interaction: walking around the physical world, interacting with real objects, and in-situ animations. The three kinds of interactions are introduced in the following paragraphs. Figure 4 shows the images of three interactions in a collaborative shopping scenario.

The first interaction is walking around the physical world. The avatar is enabled to walk around the physical world like a human. This is designed to facilitate users to have a sense of how they move around after trying on clothes from a third-party perspective. To make the avatar walk, the user first needs to look at a point in the real

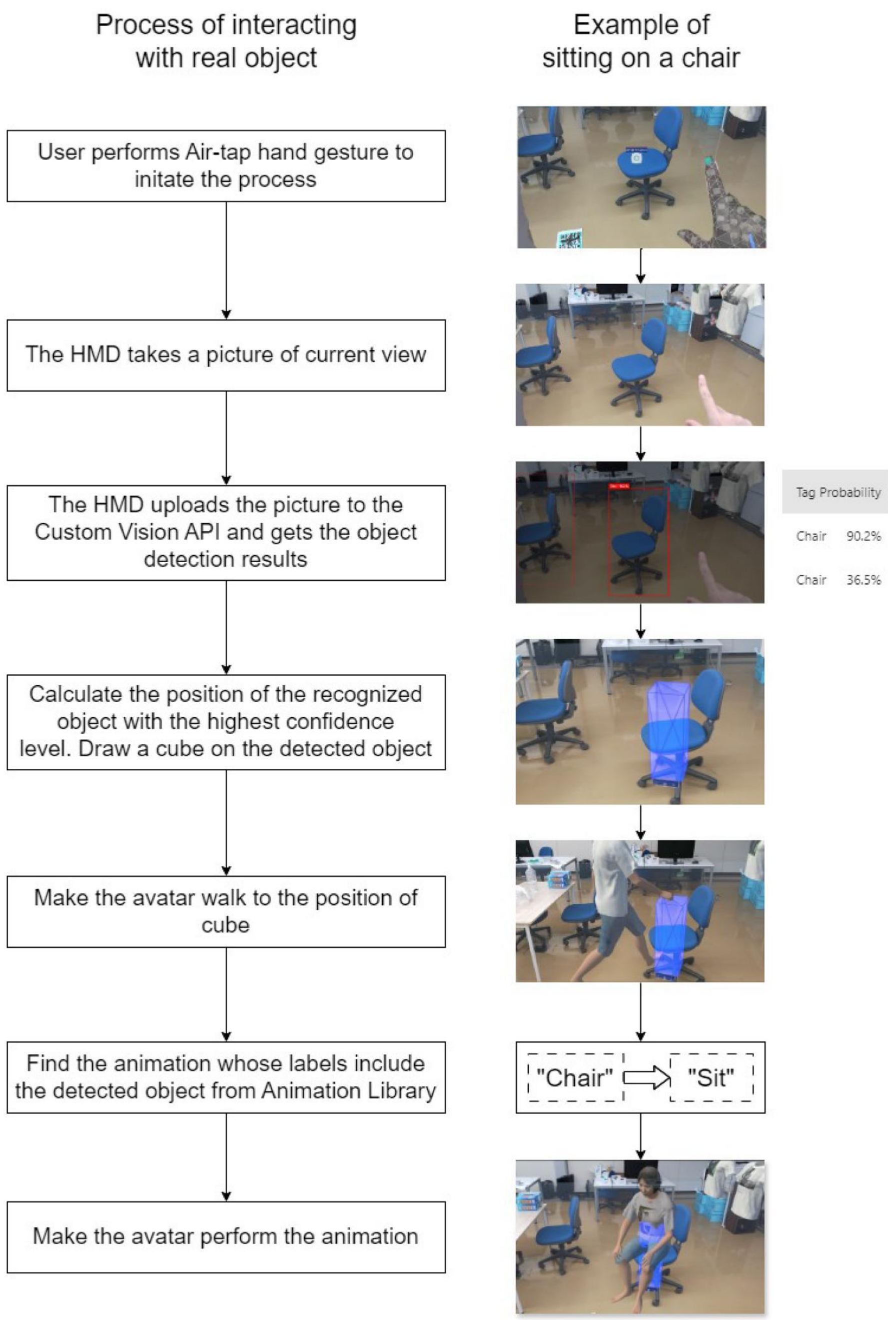

Figure 5. The process of building an animation library for a personalized avatar.

environment, and then the user performs an Air-Tap gesture (a hand gesture in HoloLens). Then the avatar will walk toward that point from its current location. The avatar's walking is accomplished by combining a human's walking animation with the avatar's position change.

The second interaction is interacting with real objects. We propose to enhance the interactive capabilities of avatars to enable more human-like interactions with real physical world environments. This feature leverages avatars' interactions with real objects to simulate a user's daily activities. So when users try on virtual clothes, they can imagine and evaluate how the clothes will fit into their daily lives. This immersive experience is designed to give people a more comprehensive understanding of the practicality and esthetics of clothing in various daily scenarios. The process of an avatar interacting with a real object is shown in Figure 5. The process is initiated with the user performs an Air-tap gesture. For example, the user can look at a chair and make an Air-tap gesture to make the avatar interact with the chair. The HMD then takes a picture of the real environment from the user's current perspective. The captured picture will be uploaded to the Custom Vision API to perform object detection processing. The example in Figure 5 shows that the object detection result is that there are two chairs in the picture, and the probabilities are 90.2% and 36.5%. The system calculates the position of the recognized object with the highest probability and draws a cube on the detected object as a marker of the location of the object.

Figure 6. Examples of interacting with real objects. Left: typing on a computer. Right: doing sit-ups on a yoga mat.

Figure 7. Examples of in-situ animations. Starting from the left, they are: standing, dancing, boxing, and jumping.

Next, the avatar will be ordered to walk next to the cube. Based on the tag of the detected object, the system finds animations whose labels include the detected object from the animation library. For example, the "chair" label is included in the "sit" animation. Finally, the system allows the avatar to perform animation and complete the interaction process with real objects. In the example in Figure 5, the avatar ends up sitting on a real chair. Figure 6 shows examples of an avatar typing on a computer and an avatar doing sit-ups on a yoga mat.

The third interaction is in-situ animations. In-situ animations are designed to complement the other two types of interactions. These animations involve the avatar performing certain actions in place, actions that are not commonly observed but might be performed by users in specific scenarios. For example, when purchasing running shoes, a user might simulate running, or when buying basketball attire, they might try a jumping shot. However, these actions are typically not performed in an indoor environment. The in-situ animations thus enable the avatar to demonstrate these specific, contextually relevant actions, providing users with a realistic visualization of how the products would function in specific real-life scenarios, although within the constraints of the indoor environment. Figure 7 shows some examples of in-situ animations. The in-situ animations come from the animations in the established animation library that do not require objects to complete the action. Users can switch in-situ animations to preview the effects of trying on clothes in different actions.

3.4. Shared gaze

Our system incorporates shared gaze into collaborative shopping to facilitate shoppers in a multi-user AR shopping scenario.

3.4.1. Gaze tracking

To implement shared gaze, we track the users' eye movements using an AR HMD equipped with eye-tracking sensors. In order for eye tracking to work accurately, every user needs eye tracking calibration when first using it. The eye-tracking sensors provide information about the origin and direction of the user's gaze. The gaze-tracking module of our system uses the information provided by gaze-tracking sensors to emit a gaze ray whose origin and direction are consistent with the gaze-tracking information. In addition to the gaze origin and direction, the user's gaze point is also calculated. We set the default length of the gaze ray to two meters, so the default location of the gaze point is the end point of the gaze ray, which is two meters away from the gaze origin. When the gaze ray collides with the real environment or virtual object, the gaze point is at the intersection point of the collision. In general, in the gaze-tracking module, each user's gaze origin and direction and the user's gaze point can be obtained.

3.4.2. Gaze data synchronizing

The gaze data synchronizing module mainly synchronizes each user's gaze data (gaze origin, gaze direction, and gaze point) obtained in the previous step to each user. We use a fully connected network to synchronize users' gaze data, that is, each user has direct data exchange with all other users. Each user is constantly sending their own gaze data, and at the same time, each user is constantly receiving gaze data from other users. These gaze data are calibrated to the same coordinates. The data transmission is implemented using the UDP protocol. In this way, efficient gaze data synchronization within a small range of users is achieved.

3.4.3. Multi-user gaze visualization

Most applications use a cursor as the location indicator of gaze or use a gaze ray as the direction indicator of gaze. Our system combines the cursor and gaze ray to represent both gaze location and direction. We use a virtual HMD model superimposed on the gaze origin of the use to emphasize the start point of the gaze and the user who owns the gaze. When the user's gaze direction changes, the virtual HMD will also rotate to that direction. The gaze points of users are represented using spheres with different colors. We use magenta to illustrate the gaze point of self and use cyan-blue to illustrate the other users' gaze points. There is a translucent blue ray between the gaze origin and the gaze point, representing the gaze direction of the user.

During the design and development phase of the prototype, we showcased it to a group of sample users and gathered initial feedback through interviews, enabling us to iterate the design. We discovered that the gaze rays may be distracting to users in the multi-user scenario. Therefore, we improved the visualization of shared gazes as follows:

- Remove the gaze ray of the self-user. Only showing the gaze ray of the other user. The gaze points of all users will be shown.

Figure 8 shows the first-person view of the final version of the shared gaze interface. The magenta sphere stands for the photographer user' s own gaze point. The user wearing HoloLens in the picture represents the partner of the photographer user. The cyan-blue sphere indicates the gaze point of the partner user. The white virtual HMD indicates the head position and rotation of the partner user. And the ray starting from the virtual HMD and ending at the cyan-blue sphere stands for the gaze ray of the partner user.

4. Implementation

The implementation of our collaborative AR shopping system, which integrates interactive personalized avatars and shared gaze cues, requires a multifaceted approach encompassing software development and hardware. Here, we

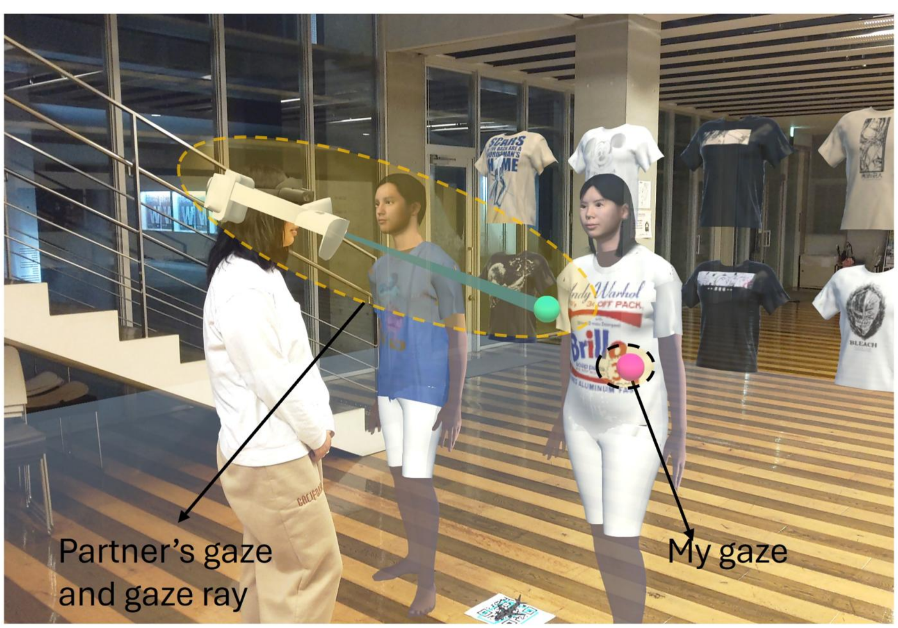

Figure 8. The visualization of shared gaze.

Table 1. The pre-experiment questionnaire.

Questions	Items	Count[a]
Gender	Male	23(21)
	Female	11(9)
Age		
How often do you shop online?	Never or less than once a month	0(0)
	Once to 4 times a month	21(20)
	5 to 9 times a month	9(7)
	More than 10 times a month	4(3)
Which one better describes you when buying clothes?	I prefer shopping for clothes by myself.	21(17)
	I am more likely to go shopping with others for clothes.	13(13)
What is your experience of AR?	I never knew about AR before.	2(0)
	I heard about AR.	8(8)
	I have experiences of using AR applications.	13(11)
	I am familiar with using AR applications.	5(5)
	I am familiar with using and developing AR applications.	6(6)
If you have used an AR application, what kind of device have you used?	Smartphone	22(20)
	Head-mounted display	10(10)
	Other device	0(0)
	Never used	2(0)
Your personal information needs to be collected before the experiment. Your data will not be used for any purpose other than this experiment. Is this acceptable to you?	Acceptable	32(30)
	Not acceptable	2(0)

[a]The number in parentheses represents the count of participants who were finally selected to participate in the experiment.

outline the key components and strategies involved in the implementation process.

4.1. Software development

The whole application is developed using the Unity 3D game engine. We create an AR shopping environment that overlays the physical world using MixedRealityToolkit. This environment includes 3D models of products, virtual shelves, and other retail elements. We use Photon Engine to manage the multi-player user scenario. Users can automatically connect to the server upon entering the application.

4.2. Hardware

The effectiveness of the AR shopping experience is heavily dependent on the hardware used. Key hardware is the see-through type AR HMD, HoloLens 2. HoloLens 2 supports hands-free AR experience which can be manipulated using hand gestures. HoloLens 2 also is equipped with cameras and eye-tracking sensors, which is suitable for our prototype. The entire system is developed using a PC with a Windows 10 operating system with an Intel i9 processor.

5. Evaluation

We conducted user studies both quantitatively and qualitatively to evaluate our proposal and system. As the positive effect on the user's evaluation of the avatar's personalization has already been verified in previous works, we are not going to reevaluate the avatar's personalization in this paper. Our focus is the impact of the interactivity of virtual avatars and the design of shared gaze in collaborative shopping.

5.1. Participants

Before conducting the experiment, we performed a statistical power analysis using G*Power to calculate the sample size. To test the medium effect size f of 0.25, the minimum sample size required for this study was 24 participants with an error probability α of 0.25 and statistical efficacy $(1 - \beta)$ of 0.80.

We recruited participants from our campus. We posted a participant recruitment announcement on the campus. The announcement stated the content of the experiment, the location of the experiment, and the appreciation gift provided to participants. To encourage participation, we promise to be rewarded with a thousand Japanese Yen for participating in the experiment. Interested individuals were asked to fill out a pre-experiment questionnaire (via either an online Google Form or a paper document). The questionnaire gathered demographic information, such as gender and age. It primarily focused on participants' shopping habits and their AR knowledge. Therefore, our pre-experiment questionnaire included questions shown in Table 1.

We received a total of approximately 34 inquiries regarding participation. Since our experiment involves the use of cutting-edge AR equipment that is not very commonly used, we excluded participants who lacked any knowledge of AR. Additionally, the experiment required the creation of personalized avatars, necessitating the collection of personal data. Besides, Ivanov, Mou, et al. (2023)'s research reveals that privacy concerns negatively impact user behavior and their willingness to engage with virtual try-on technology. Consequently, individuals who have concerns about sharing their personal information were also excluded. Ultimately, thirty participants were selected for the final experiment (21 males and 9 females).

The table presents the results from the pre-experiment questionnaire completed by the participants selected for the experiment. Their ages ranged from 21 to 28. All participants had experience with online shopping and possessed some understanding of AR. Of these, six were well-acquainted with AR and had experience in its development. Ten participants had experience using HMDs. Regarding shopping preferences, thirteen participants preferred shopping for clothes with others, while seventeen preferred to shop alone.

5.2. Experiment setups

The experiment was conducted in an office furnished with accommodation, including a desk, chair, computer, and yoga mat. The room size is approximately 7 by 8 square meters. A printed QRcode was pasted on the floor in the center of the office room and was used to synchronize the coordinates of the AR environment. The device used in the experiment is the see-through HMD HoloLens 2.

Participants were divided into pairs randomly and were asked to simulate a realistic shopping scenario with their partners. A pair of participants were required to wear HoloLens 2 across the experiment.

During each trial, a total of 20 garment items were displayed to the participants, rendered as 3D models, which were made from the actual garment products of an established e-commerce website. Each garment item had 8 sizes to select from, from XS to 4XL according to the real garment size. The types of garments include T-shirts, shirts, short pants, trousers, skirts, and sweaters (Appendix B). These 3D garment models are arranged into two blocks located in two directions of the room, each block has two rows, and each row contains 5 garment items. To eliminate the transfer effect, the garment items of the four conditions are different. So there are 80 garments in total. The fit visualization fidelity is compared in Appendix C.

5.3. Experiment design

5.3.1. Independent variables and conditions

This experiment aims to evaluate the effects of Shared and Interactive Personalized Avatar on collaborative AR shopping systems. The experiment follows a two-factor repeated measures design (2 * 2) to investigate the effects of the interactivity of personalized avatars (levels: static and interactive) and shared gaze (levels: with and without) on the collaborative shopping experience. Therefore, four different conditions (Table 2) were used in the experiments.

We defined the personalized avatar with two levels:

- Static personalized avatar: The personalized avatars stand static at a fixed position.
- Interactive personalized avatar: The personalized avatar can perform actions and walk. The personalized avatar can also interact with the real environment. For example, the avatar can sit on a chair, type on a computer, and do sit-ups on a yoga mat.

Table 2. Four conditions used in the experiment.

	Static personalized avatar	Interactive personalized avatar
Without Shared Gaze	Control	Only interactive PA
With Shared Gaze	Only shared gaze	Combined

The shared gaze's two levels are defined as below:

- Without shared gazes: The participant cannot see the gaze of himself or his partner.
- With shared gazes: The participant can see the gaze of himself and his partner in real-time. The participant's own gaze is represented by a magenta ball, and the companion's gaze point is represented by a cyan-blue ball. The direction is represented by the ray emitted from the companion's head position.

5.3.2. Procedure and tasks

The procedure of the experiment mainly has seven steps. Each trial took almost 1 hr.

1. Training in using HoloLens 2. Before the experiment begins, each participant was required to practice the use of HoloLens and learn the basic operations of HoloLens. This is to reduce the impact of unfamiliarity with the equipment. The tutorial for learning is provided by HoloLens' official application store.
2. Calibration of Gaze. The Gaze of each participant is different. To eliminate the error of eye-tracking, HoloLens needs to calibrate the gaze of each participant. The calibration is processed by the HoloLens application automatically. Participants need to follow the instructions of HoloLens.
3. Introduction and explanation of experiment contents to each participant. Each participant was informed of the experimental content through detailed experimental design documentation and explanation by the researcher.
4. Signing of Agreement. The experiment follows the restrictions of Waseda University Research Ethics Measures. Each participant needs to sign a form of agreement.
5. Participants are divided into groups. Each group has two participants. This is randomly assigned.
6. Performing an experiment. The experiment followed a within-subject design where the participants tested all four conditions in the user study. Participants needed to select clothes for themselves and their partners in all 4 conditions. To reduce the effects of learning and transfer between conditions, the order of testing of the 4 conditions was randomly assigned to each participant. And the clothing products are different in each case. The performance time of each condition was recorded.
7. Data collection. During the experiment, participants' thoughts and feelings were reported via a think-aloud protocol and were recorded using audio recordings and notes. After completing all four conditions, participants were asked to fill out a questionnaire that assessed the user experience in each condition in terms of:

Enjoyment, *Usefulness*, *Ease of Use*, *Communication*, *Co-presence*, and *Future Use*. Then we asked all participants to rank the four systems based on their preferences. Afterward, participants were interviewed about the whole system. Finally, participants were paid for their participation, ending the experiment.

5.3.3. Measurements

The participants completed the questionnaire using a 7-point Likert scale (ranging from -3 "Strongly Disagree" to 3 "Strongly Agree") adopted from existing research (Table 3). In order to measure the shopping experience, we selected *Enjoyment* and *Usefulness* to measure the hedonic value and practical value of the shopping experience. *Enjoyment* was measured using a 4-item scale from Childers et al. (2001) ($Chronbach's\ \alpha = 0.912$, $M = 2.019$, $SD = 1.269$). The items on *Usefulness* were adapted from Yi et al. (2015) and Davis (1989) ($Chronbach's\ \alpha = 0.902$, $M = 1.815$, $SD = 0.892$). Since the advanced functions in this experiment are accompanied by complex operations, we would like to evaluate whether interactive, personalized avatars and shared gaze increase the complexity of use compared with the basic system, which may hinder users from using it. So the system's *Ease of Use* was measured. And the items on user's perceived *Ease of Use* were also adapted from Davis (1989) ($Chronbach's\ \alpha = 0.946$, $M = 1.933$, $SD = 1.707$). Communication is critical in collaborative work, related to establishing a common ground between collaborators and the efficiency of collaborative work. Interactive personalized avatars and shared gazes may enhance consumer communication in the context of collaborative shopping. To confirm this, we measured *Communication*. The items on *Communication* were taken from Hilken et al. (2020) ($Chronbach's\ \alpha = 0.872$, $M = 2.036$, $SD = 1.184$). The items on *co-presence* ($Chronbach's\ \alpha = 0.848$, $M = 1.996$, $SD = 1.097$) and *Future Use* ($Chronbach's\ \alpha = 0.899$, $M = 2.017$, $SD = 1.187$) were adapted from H. Kim et al. (2013). *Co-presence* is critical for evaluating the effectiveness of AR systems in simulating real-life interactions. And measuring users' future usage intentions can provide insights into a product's long-term sustainability and market potential.

5.4. Results

From the experiment, we successfully gathered two kinds of data: quantitative data derived from the questionnaires and qualitative data obtained through the transcription of think-aloud sessions and interviews. We performed quantitative analysis on the former and qualitative analysis on the latter, both of which are elaborated upon in the following sections.

5.4.1. Quantitative results

In our quantitative analysis, the objective was to investigate the primary effects and interactions of shared gaze and interactive personalized avatar (PA) on participants' evaluation of each experimental condition and to elucidate the underlying reasons for these observed differences. As each participant tested all four conditions (within-subjects design), we analyzed the quantitative data using a two-factor repeated measures ANOVA.

The results of ANOVA (Table 4) revealed significant main effects for most variables with shared gaze and interactive personalized avatar, except for *Ease of Use*. The mean scores of variables in four conditions are shown in Figure 9.

The ANOVA results showed strong main effects for Shared Gaze and Interactive Personalized Avatar on users' perceived *Communication*. And the two factors also had obvious effects on users' perceived *Co-presence*. The results of ANOVA also reported there is a significant difference when both Shared Gaze and Interactive Personalized Avatar were present on *Communication*. Figure 10 shows the interaction effects on *Communication* and *Co-presence*. Scores for *Communication* and *Co-presence* are higher when Shared Gaze is present, and even higher when Personalized Avatar is interactive, suggesting a synergistic effect. We tested the impact of Shared Gaze and Interactive Personalized Avatars on the shopping experience of users in an AR collaborative shopping system, with a focus on the hedonic (enjoyment) and utilitarian (usefulness) dimensions. The analysis revealed that both Shared Gaze and Interactive Personalized Avatars independently contributed to increased perceptions of enjoyment and usefulness among users. The main effects for Shared Gaze were significant in terms of *Enjoyment* and *Usefulness*, indicating a significant hedonic and utilitarian

Table 3. Constructs and measurement items.

Constructs	Measurement items
Enjoyment	(EM1) Shopping with this shopping technology would be enjoyable.
Childers et al., (2001)	(EM2) Shopping with this shopping technology would be fun.
	(EM3) Shopping with this shopping technology would involve me in the shopping process.
	(EM4) Shopping with this shopping technology would be exciting.
Usefulness	(UF1) This system is helpful for me to evaluate the product.
Yi et al., (2015)	(UF2) This system is helpful in familiarizing me with the product.
Davis, (1989)	(UF3) This system is helpful for me to select the product that fits me.
	(UF4) This system is useful in buying what I want.
Ease of Use	(EU1) This system is easy to use.
Davis, (1989)	(EU2) This system does not require a lot of mental effort.
Communication	(CM1) Using the system allowed me to show (see) my partner how my recommendation fits me.
Hilken et al., (2020)	(CM2) Using the system allowed me to make (get) the recommendation visible to (from) my partner.
	(CM3) Using the app allowed me to communicate with my partner easily.
Co-presence	(CP1) I can notice my partner easily.
H. Kim et al., (2013)	(CP2) My partner can notice me easily.
Future Use	(FU1) I would like to use this system in the future.
H. Kim et al., (2013)	(FU2) I predict I will use this system in the future.

Table 4. Results of ANOVA.

	Main effects						Interaction		
	Shared gaze			Interactive PA			Shared gaze * interactive PA		
	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Enjoyment	40.624	<0.001***	.583	17.332	<0.001***	.374	.864	0.360	.029
Usefulness	27.625	<0.001***	.488	52.714	<0.001***	.645	2.867	0.101	.090
Ease of Use	.720	0.403	.024	3.053	0.091	.095	.195	0.662	.007
Communication	29.521	<0.001***	.504	22.208	<0.001***	.434	12.560	0.001**	.302
co-presence	30.345	<0.001***	.511	10.976	0.002**	.275	9.693	0.004**	.251
Future Use	15.676	<0.001***	.351	7.864	0.009**	.213	.173	0.681	.006

**$p < 0.01$; ***$p < 0.001$.

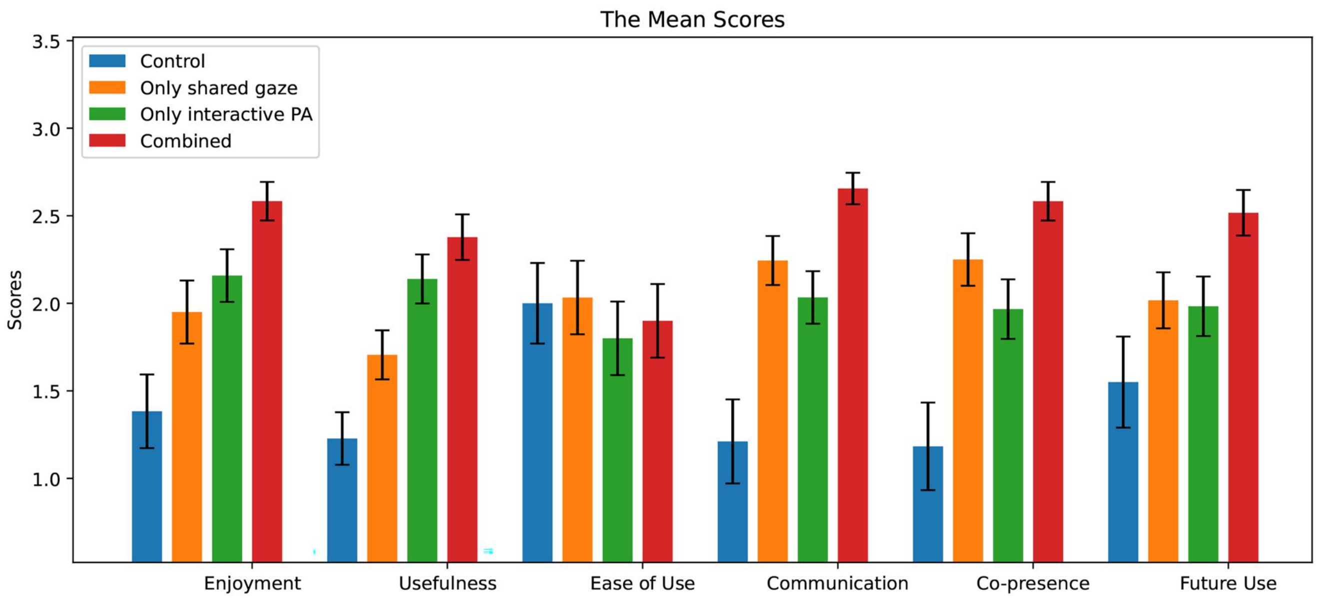

Figure 9. Mean scores of measurements across 4 conditions. Error lines represent ±1 standard error of the mean.

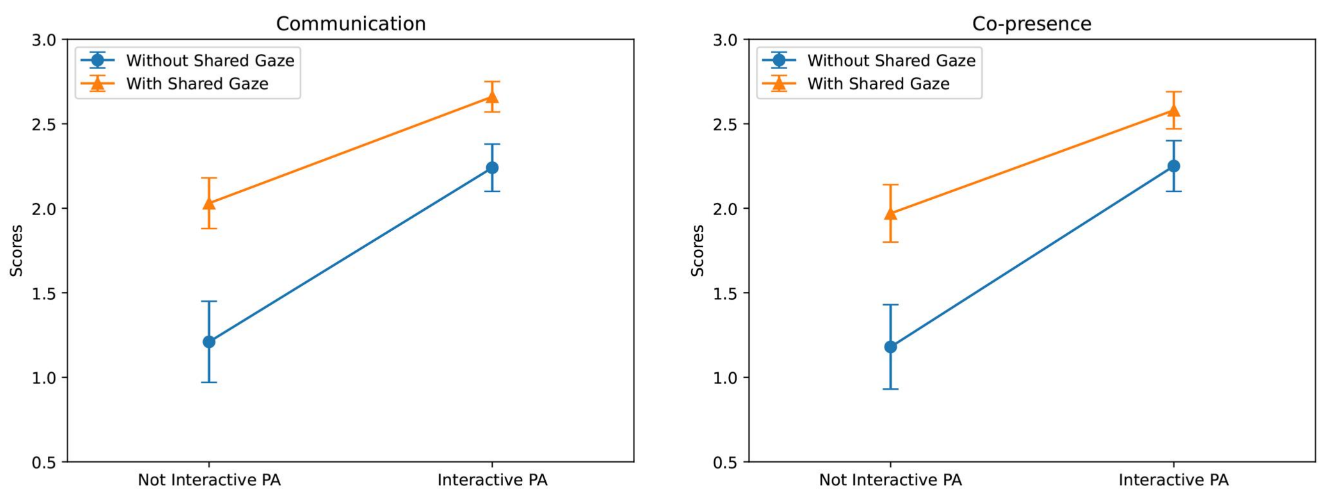

Figure 10. Interaction effects of interactive personalized avatar and shared gaze on communication and co-presence. Error lines represent ±1 standard error of the mean.

enhancement through this feature. Similarly, Interactive Personalized Avatars also significantly affect the user's perception of *Enjoyment* and *Usefulness*. However, the interaction between shared gaze and interactive personalized avatars did not significantly affect enjoyment and usefulness, suggesting that the combination of these two features does not necessarily increase enjoyment and usefulness. We also evaluated the future use of each condition. The results revealed that participants were inclined to the conditions with Shared Gaze or Interactive Personalized Avatar. Although the ANOVA results showed that there was no significant interaction effect of two features, the mean score of the combination of two features was highest. Moreover, the score of the condition where only Shared Gaze exists is similar to the condition where only Interactive Personalized Avatar exists. The results of ANOVA show that Shared Gaze and Interactive Personalized Avatar and their interaction have no obvious effects on the system's *Ease of Use*.

In order to understand whether the participants' prior AR experience has an impact on their scores in the experiment, we have tested the correlation between the participants' prior experience with AR technology and their scores on each variable at a significant level of 0.05. The test result shows that there is no significant correlation between the participants' prior experience with AR and their reported scores (Appendix A).

5.4.2. Preference for the systems

We asked participants to rank the four conditions based on their personal preference for collaborative AR shopping. Overall, as Figure 11 shows, the combination of shared gaze and the interactive personalized avatar was mostly preferred as their first choice (26 out of 30) followed by control (2 out of 30), with the remaining two tied for third (1 out of 30). The pairwise comparison conducted using the Friedman test revealed a significant difference in ranking results across four conditions ($\chi^2(3) = 54.120$, $p < 0.001$). We performed a Wilcoxon Signed-rank test to explore the differences between pairs across the four conditions, as Table 5 shows. The results showed significant differences ($p < .05$) between all cue pairs except Only Shared Gaze and Only Interactive Personalized Avatar. This shows that the combination of Shared Gaze and Interactive Personalized Avatar was ranked and preferred in our tasks.

5.4.3. Qualitative results

We collected qualitative results from think-aloud sessions and interviews. We want to investigate users' thoughts deeply in qualitative analysis, hoping to discover characteristics beyond quantitative analysis's scope. For the after-experiment interviews, we asked the participants about their thoughts on collaborative shopping using the system and their reasons for ranking four conditions. The qualitative data collected are shown in Table 6.

For examining the product, participants highlighted the benefits of 3D personalized avatars, allowing them to view garments from multiple degrees, which is not easy to achieve in physical stores. Moreover, the process of trying on clothes is quick, so that the participants can 'try on' a lot of clothes in a short time, improving the efficiency of examining products. However, P5 said, "I feel that the color of the 3D model is not very realistic. It may be a problem with the equipment, but this problem affects my judgment of the clothes." This implies that the quality of the examination is highly related to the devices.

Through the think-aloud protocol, we found that participants were highly engaged in the process of selecting and trying on clothes with their partners, and there was lots of laughter between them. For example, P3 said, "It' s fun to choose clothes with friends, just like going to an offline mall together." P12 also said, "I can immerse myself in the shopping environment and hope to use it in the future." And P21 said, "I think interacting with avatars brings a lot of fun, which is crucial to the system I choose to use in the near future." Participants tend to seek fun during the interaction with avatars.

The collaboration with the partner was found to be effective in the decision-making process. Participants can get advice from their partners and sometimes try out new styles. For instance, P30 said, "Although the clothes my partner picked for me were different from my usual dressing style, I thought they looked pretty good after seeing my avatar try them on, and I wanted to try a new style."

In the aspect of sharing gaze with a partner, participants reported that this feature facilitated communication and made it easier for them to follow their partners' focus of interests, especially when there were a lot of products (P27 said: "I feel that shared gaze is very useful when there are many products.") Sharing gazes between shoppers first facilitates communication between shoppers about clothes, such

Table 5. Result of Wilcoxon Signed-rank test.

Condition1-Condition2	Z	p
Control - Only shared gaze	−2.831	0.005**
Control - Only interactive PA	−3.510	<0.001***
Control - Combine	−4.801	<0.001***
Only shared gaze - Only interactive PA	−1.321	0.186
Only shared gaze - Combined	−4.757	<0.001***
Interactive PA - Combined	−4.519	<0.001***

$^{**}p < 0.01$; $^{***}p < 0.001$.

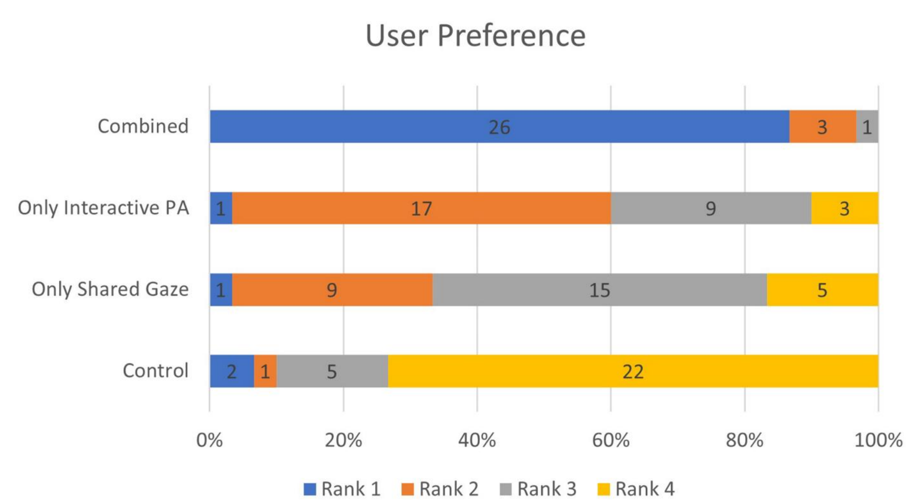

Figure 11. User preference-based ranking results (Rank 1 is the most preferred).

Table 6. Illustrative excerpts and main conclusions of qualitative analysis.

Category	Conclusion	Excerpt
Examining the product	The 3D interactive personalized avatars provides a dynamic and efficient way to review clothing, but issues with color realism can affect judgment.	"The 3D personalized avatar enables me to examine the garment from 360 degrees of view, which is hard to achieve in a real shop." "Using this system, I can try on a large number of clothes quickly and easily." "The interactive personalized avatars let me review products dynamically. Sometimes I find that a piece of clothing looks good when standing, but not when sitting down." "I feel that the color of the 3D model is not very realistic. It may be a problem with the equipment, but this problem affects my judgment of the clothes."
Perceived enjoyment	Collaborative AR shopping with friends enhances enjoyment and immersion, akin to offline shopping experiences.	"It' s fun to choose clothes with friends, just like going to an offline mall together." "I can immerse myself in the shopping environment and hope to use it in the future." "I think interacting with avatars brings a lot of fun, which is crucial to the system I choose to use in the near future."
Collaboration with a partner	Collaboration with a partner can affect style choices and decision-making.	"I feel that when I am indecisive, the advice given by my companions is very useful." "Although the clothes my partner picked for me were different from my usual dressing style, I thought they looked pretty good after seeing my avatar try them on, and I wanted to try a new style."
Sharing Gaze with a partner	Shared gaze is convenient and facilitates communication, but it can sometimes be distracting.	"I will follow the partner's line of sight through the shared gaze to see the clothes that the partner is interested in, which facilitates communication." "I only need to look at a piece of clothing and say, "Look at this," and my companions will know which piece of clothing I'm talking about without having to point with my hands, which is very convenient." "I feel that shared gaze is very useful when there are many products, but it is not necessary when there are few products, and it will be distracting." "I feel that shared gaze interferes with my observation of products, and I hope to turn it off." "I tend to turn off shared gaze when choosing clothes for myself, and turn it back on when choosing clothes for the other person."
Interaction with avatar	Avatar interaction can be engaging but may lead to confusion and challenges in locating avatars.	"This is really amazing, I think it's really fun to have my avatar sitting on the chair I usually sit on." "Sometimes after the avatar is moved, I can' t find my own and my partner' s avatars." "When I instruct my avatar to walk, I can imagine myself walking back and forth. But I don't need actually to move at all." "I am not good at letting avatars interact with real objects." "The Interactive personalized avatar is fun, and I find it fascinating to be able to play with friends using it."

as deixis instructions when selecting clothes. According to our observation of the participants, we found that when the participants asked or gave their partner's opinion, they would look at the clothes directly or try the clothes on their personalized avatars and say:" How about this one?" At the same time, we also observed that when browsing clothes, two shopping partners often follow the other's gaze, intending to see what kind of clothes their partner is looking at and learn about the clothes their partner is interested in. Sharing each other's gaze in collaborative shopping can enhance the awareness between shoppers and allow shoppers to understand each other's interests, which is very useful for collaborators to establish a common ground. However, three participants felt that the shared gaze could be distracting and preferred to disable it, indicating a need for customization of user experiences in such systems.

The interaction of personalized avatars with real objects has a positive effect on the hedonic value of the shopping experience. During the experiment, most subjects expressed surprise and pleasure when seeing their personalized avatars sit accurately on chairs or interact with objects in the physical world. For example, one participant said: "This is really amazing, I think it's really fun to have my avatar sitting on the chair I usually sit on." Most experimenters will try multiple times to have their avatar sit on a chair or interact with other real objects because they find such interactions very interesting. We believe that this kind of interaction, such as sitting on a chair and allowing a virtual 3D personalized avatar to interact with real objects, mainly enhances the hedonic value of the collaborative shopping experience. Making the personalized avatar interactive can make users feel more engaged. For example, P30 said, "When I instruct my avatar to walk, I can imagine myself walking back and forth. But I don't need actually to move at all." Although interacting with avatars is fun, there are still some problems. First, P25 reported that it was difficult to locate avatars after they had been moved. And P16 reported that making avatars interact with real objects was complicated and hard to achieve. If a user feels that interacting with an avatar is complicated, the user will tend not to interact.

6. Discussion and implication

With this research, we propose a design method for the collaborative AR shopping system using interactive personalized avatars and shared gaze cues. We further provide an understanding of how interactive personalized avatars and shared gaze enhance the user experience of collaborative shopping in a multi-user AR environment. We examined the effects of interactive personalized avatars and shared gaze between customers through two-factor repeated measurement.

The results of the user study showed that the interactive personalized avatar (compared with a static personalized avatar) and shared gaze significantly affected users' perception of enjoyment, usefulness, communication, co-presence, and future use of the system. The combination of interactive personalized avatars and shared gaze further enhances perceived communication and co-presence. The results of our user experiments are consistent with previous research. According to some studies, the experience of customers is shaped by various interactions between customers and objects (Esfidani & Izadi, 2023). The customer experience is made up of a series of interactions between customers and products/corporations/services. Previous researchers reported the importance of interaction with shopping companions and collaborative shopping platforms. Our proposed system enhances the interaction with the collaborative shopping system by using AR technologies. With the interactivity level of personalized avatars increases, consumers' interactions with the whole shopping system also increase, increasing the value of consumers' shopping experience. Sharing gazes between consumers also increases the shopping interaction in terms of consumer-consumer conditions (Wanick & Bazaki, 2020). The AR presentation of garment products with the function of trying on clothes can give customers a novel and interesting shopping experience as well as provide a way for customers to preview the try-on effect of clothes faster and more conveniently, increasing the hedonic value and practical value of a collaborative shopping system.

Using interactive personalized avatars, customers can have more and deeper interactions with products, shopping companions, and even the real environment. For example, customers can ask the avatar to make desired actions to dynamically preview the try-on effect of clothes, and the avatar can interact with the real environment and observe from different angles, making it easier to judge the try-on effect in the real environment. Moreover, the personalized avatar is customized according to the user's body shape and appearance, facilitating users to have an impression of their own try-on effect, also increasing the embodiment of users to improve co-presence (H. Kim et al., 2013). Users can also have more interactions and communications through interactive personalized avatars with each other. For example, users tend to dress interactive personalized avatars in different clothes to showcase their outfits and ask their companions for advice. Some users also use interactive personalized avatars to express their emotions to their companions. The fidelity of avatar-based fitting visualization and selection of garments available for try-on also play important roles in this context. Although in this study, the clothing models were made based on clothing information on real shopping websites, and each user has his or her own personalized avatar that matches his or her body shape and appearance, such a try-on effect is still different from the real try-on experience due to limitations of 3D modeling technology and computer graphics technology. The next way to improve the visualization of virtual try-on could be to increase the realism of the fabric. Consumers also need a variety of choices for garments, so varieties and even better garments that conform to consumers' shopping preferences are necessary.

The shared gaze feature in our AR collaborative shopping system is critical in enhancing interpersonal interactions and communication between shopping companions. For example, shopping companions can see where others are looking to understand their interests and preferences. The shared gaze interface is particularly beneficial in a crowded and diverse shopping environment, where navigating various products can be overwhelming. The effectiveness of shared gaze in our system also aligns with previous works. Studies have shown that shared attention facilitates collaborative tasks (Piumsomboon et al., 2018; Zhang et al., 2017). This shared attention is adequate for user decision-making and connection in a shopping context. In addition, participants reported that sharing their gaze with others was interesting and novel, improving the perceived enjoyment.

The combination of interactive personalized avatars and shared gaze further enhances perceived communication and co-presence in collaborative shopping. This may indicate that users not only want more interaction with the shopping system but also want more interaction with their partners. These technologies enhance users' enjoyment of the shopping experience and promote deeper connections between users.

In terms of practical implications, we explore how interactive personalized avatar and shared gaze technologies can be applied to improve the design, development, and marketing strategies of AR shopping systems to enhance user experience and satisfaction. For Designers of shopping system using AR technology, the integration of interactive personalized avatars and shared gaze technology presents a significant opportunity for enhancing the user interface and user experience in AR shopping systems. Designers can leverage interactive avatars to create more engaging and intuitive shopping environments. For instance, by allowing avatars to dynamically showcase clothing items as they would appear to the shopper, designers can provide a more realistic and personalized shopping experience. Additionally, sharing gaze technology can streamline navigation through virtual stores, enabling shoppers to intuitively follow their companions' lines of sight, thereby simplifying the product discovery process. For developers, it is necessary to consider different people's acceptance of new technologies and conduct customized development. We have found that some participants are not familiar with the manipulation of the HMD, so they feel frustrated when they cannot perform the right manipulations. One participant reported that the color of the AR display is not realistic. Marketing professionals can harness these technologies to conduct innovative campaigns that allow consumers to interact with products in immersive ways. For example, marketers can design experiences where users can virtually try on outfits and receive instant feedback from friends, thereby creating a social shopping experience. Additionally, analyzing user behavior data from these interactions can help marketers tailor their strategies to better meet consumer preferences, optimizing targeted advertisements and improving overall marketing effectiveness.

7. Conclusion

In this paper, we presented a novel approach to collaborative shopping in a multi-user Augmented Reality (AR) environment, emphasizing the integration of interactive personalized avatars and shared gaze cues. Compared with previous research, our proposal enables the users to have more realistic and interactive personalized avatars and experience the shopping process in a collaborative and immersive way. We conducted user studies to comprehensively understand how interactive personalized avatars and shared gaze cues can enhance the collaborative shopping experience.

Firstly, our findings demonstrate that interactive personalized avatars improve user experience in the shopping process from enjoyment, usefulness, communication, co-presence, and future use. By allowing users to visualize garments on avatars that reflect their own body shape and appearance, these avatars provide a more realistic and personal shopping experience. The high interactivity of personalized avatars leads to higher user satisfaction.

Secondly, sharing gaze cues between collaborators also improves users' enjoyment, usefulness, communication, co-presence, and future use. Moreover, incorporating shared gaze cues with interactive personalized avatars further fosters a sense of co-presence and improves communication among users. This feature simulates natural human interactions in physical shopping environments and enhances collaboration by allowing users to intuitively share and understand each other's interests and preferences.

However, our research has limitations. The study was conducted within a specific demographic and shopping context, which may not represent the broader population. Future research should explore the applicability of these findings across different demographics, including varying age groups, cultural backgrounds, and shopping preferences. Additionally, as technology continues to evolve, there is a need to continually update and refine the AR system to keep pace with advancements in hardware and software. Except for garments, future iterations of the system could be a study dedicated to evaluating specific AR affordances in a consumer-oriented application like home furnishing could provide deeper insights into the practical benefits of AR features.

In conclusion, our research underscores the significant potential of AR technologies in transforming the shopping landscape. Interactive personalized avatars and shared gaze cues in a collaborative AR shopping environment can create a more enjoyable, efficient, and socially connected shopping experience.

Note

1. https://youtu.be/wrMuyrzcHFs

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ORCID

Shihui Xu http://orcid.org/0000-0002-8926-0014
Like Wu http://orcid.org/0000-0002-2654-7966
Wenjie Liao http://orcid.org/0009-0001-5062-9507
Shigeru Fujimura http://orcid.org/0009-0003-3361-8050

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About the authors

Shihui Xu received her B.Eng degree from Southeast University, Nanjing, China, in 2018 and her Master's degree from the Graduate School of Information, production, and Systems, Waseda University, Fukuoka, Japan, in 2019. She is currently a PhD student at Waseda University. Her research interest is human-computer interactions.

Like Wu received a B.Eng degree in computer science from the Hubei University of Education, Hubei, China, and a Master's in Engineering from the Waseda University, Fukuoka, Japan, in 2018 and 2022. He is currently a PhD student at Waseda University. His research interest is Human-computer Interaction.

Wenjie Liao received a B.Eng degree from Sichuan University, Chengdu, China, in 2021 and a Master's degree from the Graduate School of Information, production, and Systems, Waseda University, Fukuoka, Japan, in 2022. He is currently a PhD student at Waseda University.

Shigeru Fujimura completed his education at Waseda University, earning a doctorate in Engineering in 1995. He worked at Yokogawa Electric Corporation and its subsidiary before becoming a professor at Waseda University, specializing in software engineering and production management.

Appendix A. Correlation coefficient between the participants' prior experience with AR technology and their scores on each variable

	EJ	UF	EU	CM	CP	FU
Control	−0.081	−0.233	−0.216	0.074	−0.242	−0.246
Only Shared Gaze	−0.074	−0.134	−0.158	−0.104	0.066	−0.076
Only Interactive PA	0.146	−0.079	−0.087	0.091	−0.094	−0.012
Combined	0.279	0.139	−0.058	0.027	0.250	−0.007

Appendix B. Examples of 3D garments used in the experiment

This figure shows some examples of 3D garments generated from a real garment shopping website, used in our systems.

Figure B1. Examples of generated 3D garments.

Appendix C. Comparison of real fitting and personalized avatar fitting

This figure compares the fitting effect of a user wearing real clothes and the fitting effect of the model we made.

Figure C1. Comparison of real fitting and personalized avatar fitting.