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Enhancing shopping experience in augmented reality by customizing product manipulation modalities: A customer experience study

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A R T I C L E I N F O

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A B S T R A C T

In recent years, Augmented Reality (AR) technology has permeated various domains. This paper focuses on the critical aspect of enhancing customer interaction within AR e-commerce environments by investigating the impact of virtual product size manipulation on usability, user experience, and shopping satisfaction. We tested two manipulation modalities: an unconstrained scaling modality, enabling users to manually adjust product dimensions, and an assisted modality providing automatic 1:1 scaling. Using the Microsoft HoloLens 2 AR headset, we engaged 40 participants with small and large virtual products in shopping scenarios using these two manipulation modalities.

Results show that users found the automatic manipulation modality to provide a superior user experience, being more effective, easy, useful, and pleasant when interacting with large virtual products. For small virtual products, they expressed a preference for free manipulation. Customer satisfaction with the shopping experience is positive, however, product size and manipulation modality affect the repatronage intention.

The findings offer insights into designing AR e-commerce interfaces, highlighting that providing different manipulation modalities depending on the size of the products allows for enriching the shopping experience and improving the AR market potential.

1. Introduction

Augmented reality (AR) technology is spreading more and more in various fields, including education (Kljun et al., 2020), medical treatment and surgery (Heinrich et al., 2023), tourism and cultural heritage (Graziano and Privitera, 2020), videogame industry (Das et al., 2017), manufacturing (Hietanen et al., 2020), automotive industry (Boboc et al., 2020), and marketing (Gabriel et al., 2023). One of the most promising applications of AR is in e-commerce, where it provides an immersive and interactive environment for consumers to browse and purchase products (Chen et al., 2019; Dargan et al., 2023). The application of AR on an industrial and mass scale allows people to enjoy new shopping experiences compared to traditional e-commerce (Chen et al., 2019). Through AR, users can explore objects in more detail, see their dimensions directly in their homes, customize items, acquire more comprehensive information about the products, and increase their sense of ownership (Poretski et al., 2021). All these benefits lead to an increased willingness to purchase, which also offers significant advantages for the seller (Fu'adi et al., 2021).

Companies progressively acknowledge the necessity of investing in AR to improve the consumer experience and, consequently, maintain their leadership position and empower their brand (Parekh et al., 2020). For example, Coca-Cola, McDonald's, and General Electric have integrated AR into their marketing strategies, creating interactive advertisements and providing immersive, engaging, and innovative experiences (Scholz and Smith, 2016). Amazon has introduced AR into its platform with the "View in your room" feature (Romano et al., 2021). This feature allows users to project digital versions of products, such as furniture and appliances, into their physical surroundings and assess their appearance while wearing accessories and shoes. Similarly, IKEA

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has integrated AR into its mobile app, called “IKEA Place”, enabling customers to virtually place furniture in their homes and reduce uncertainty about how a new product will fit into their existing arrangements and designed spaces (Ozturkcan, 2021). Also retailers and professionals in the trade fair sector are open to the introduction of AR (Orso et al., 2022). Indeed, this technology would enable them to bring a larger number of products to events without incurring additional costs related to organization and transportation.

In the ever-evolving landscape of e-commerce, AR stands as a promising frontier, paving the way for transformative innovations and novel opportunities for interaction for both sellers and consumers (Farshid et al., 2018), delving into the realm of hybrid experiences. Hence, it becomes imperative that HCI research takes centre stage in enhancing customer engagement with commercial AR experiences.

This paper contributes to advancing knowledge about the elements that facilitate customer interaction within AR e-commerce environments during shopping by exploring a critical facet: the size of virtual products. In an AR environment, the computer-generated elements overlaying onto the physical surroundings can either faithfully resemble their physical counterparts or they can be displayed of a different size. The user can manipulate the virtual objects not only by moving them but also by adjusting their size, magnifying the tiny details of the object that otherwise would be hard to inspect. This design strategy can help to enrich the customer experience in an attempt to compensate for the lack of sensorial stimulation, e.g., touching the object, typical of online shopping (Hilken, 2022). The research question driving this study is whether it is more convenient for the user to have full freedom of object resizing or whether predefined resizing modalities are more helpful. We explored whether the size of the object played a role in determining this preference. Specifically, we explored two different modalities of resizing virtual objects, studying their effects in terms of usability, user experience, and satisfaction with the shopping experience. The first mode is an “unconstrained manipulation” mode, that enables the users to freely navigate and engage with virtual products by changing their size on an unconstrained scale (i.e., unconstrained object scaling). The second modality, an “assisted manipulation” mode, embeds an automatic object scaling function, granting users the ability to view products at a 1:1 scale without the need for zooming adjustments (i.e., automatic scaling). Both resizing modalities were investigated using small and large objects, namely home appliances and furnishing elements. To do this, a Microsoft HoloLens 2 AR helmet was used in a shopping scenario. During the simulated purchase task, participants manipulated virtual products of small sizes and large sizes using one of the two different modalities. The evidence provided by this study may be useful for designers and draw attention to the need to diversify the types of manipulation based on the scale of representation of virtual objects to improve the potential of the AR market.

2. Related works

2.1. Integration of AR into the shopping experience

Most e-commerce systems that utilize AR today rely on mobile applications. These applications integrate virtual objects into the physical environment by displaying them on the screen of a hand-held device. The Amazon and IKEA e-commerce applications are popular examples of such systems (Ozturkcan, 2021; Romano et al., 2021). While these applications enable users to visualize products in their real environment, they have limitations when it comes to interaction. Users can only control the positioning of the products and their horizontal rotation along the vertical axis. On the other hand, devices such as head-mounted displays (HMD; e.g., HoloLens) open up possibilities for users to manipulate items extensively. In fact, the extensive literature on object manipulation in AR, offers several solutions that can enable 3d transformations such as rotating on all axes, enlarging, shrinking, or even exploding objects into their various components. Furthermore, in the case of AR HMD, manipulation occurs directly via mid-air gestures, with the use of hand-tracking technology, overcoming the need for controllers commonly used in virtual reality (VR; Kangas et al., 2022). Such gestures can be used to implement different styles of manipulation. Indirect manipulation, for example, maps different gestures, or combinations of them, to the transformations applied on a virtual object. Several implementations based on this style can be found in literature, many of them already catalogued in a survey on object manipulation (Mendes et al., 2019) with Handlebar (Song et al., 2012) possibly being the most notorious one as it’s widely used in many commercial VR/AR applications. An important advantage of indirect techniques is to separate degrees of freedom (DOFs), with different gestures mapping different types of actions such as translation, rotation and scaling. Opposed to this concept, there is the idea of natural interaction (Bowman et al., 2012) that offers a more intuitive way to interact with virtual objects at the cost of accuracy. In fact, while in techniques such as Simple Virtual Hand (Robinett et al., 1992) a way to perform object manipulation that reflects interaction with real objects is provided, this style doesn’t offer any aid to overcome the natural limitations of the user’s physical dexterity. Hybrid techniques such as those provided by Hololens 2 development kit (MRTK) that enable both direct and indirect styles depending on the situation (e.g. if the object to manipulate is within the user’s reach or not) can be the best compromise in an AR e-commerce context, where the user interacts with both virtual products and the physical environment around them. These features make AR HMDs strong candidates for applications in the marketing field, as it has been shown that interacting with the product increases the perceived pleasantness of the product itself, provides more information about the product, and positively influences purchasing behaviour (Kang et al., 2020; Ozok and Komlodi, 2007; Wodehouse and Abba, 2016; Xu and Sundar, 2014). Recent studies pointed out that AR has a positive impact on consumers. AR allows users to see virtual objects as if they were part of the physical world, providing a more realistic and engaging shopping experience: unlike traditional online shopping, which predominantly relies on static images and textual descriptions presented on flat, endless webpages, AR shopping provides three-dimensional context-rich visualizations that enable consumers to assess product size, fit, and aesthetics more accurately (Baytar et al., 2020). This enhanced visualization capability allows customers to interact with virtual representations of products within their physical environments, effectively bridging the gap between digital and physical shopping experiences. As a result, AR significantly boosts purchase confidence by enabling more informed product evaluations and offering realistic previews, thereby reducing uncertainty and lowering return rates, common challenges in traditional e-commerce, where users must rely on their imagination to interpret 2D images (Barta et al., 2023; Guo and Zhang, 2024). This increased interactivity, along with vivid graphical representations and detailed information, enhances the flow experience (Barhorst et al., 2021), boosting purchase intention, fostering positive attitudes toward the brand (Hilken et al., 2022), enhancing the perceived pleasantness of the product, and bolstering users’ confidence in their choices (Kang et al., 2020). The ability to customize a product by changing features like shape and colour fosters a sense of psychological ownership among users (Jussila et al., 2015). Building on this, the possibility of "wearing" products through virtual try-ons—enabled by technologies used by brands like Ray-Ban (Poushneh and Vasquez-Parraga, 2017) and Sephora (Scholz et al., 2018)—further enhances consumer trust by offering a more immersive and personally engaging experience. This high level of personalization further differentiates AR shopping from traditional online shopping, where personalization is typically restricted to algorithm-driven recommendations, such as the "recommended for you" section (Zhan et al., 2022; Alimamy and Gnoth, 2021).

Despite the great potential of AR via HMD in e-commerce, a few studies in the literature have investigated the possibility of providing different modalities of interaction based on the peculiarities of the product being manipulated (Vuletic et al., 2019). The study conducted by Pham and colleagues (2018) on gestural usability in HoloLens serves as a point of reference, although not centred on the customer experience. It suggests that the size of the virtual objects, their distance from the user, and the scene in which they are displayed influence and affect the gestures that users would spontaneously make to manipulate them (Pham et al., 2018). Tatzgern et al. (2013) highlighted the need to develop specific AR interfaces to enable users to explore distant large real-world objects (i.e., buildings). They suggest that visual links - which are designed to help users understand the spatial relationship and orientation between the viewed virtual content and the actual physical objects or locations they correspond to - are valuable cues when exploring such kinds of objects and facilitate user orientation and interaction (Tatzgern et al., 2013). Indeed, objects may have different characteristics, including colour, brightness, shape, and size, prompting different adjusting actions from the user. For example, users may need to shrink a product that is very large in its real size (e.g., the size of a car) or enlarge very small objects (e.g., the size of a smartwatch) to better inspect it. Alternatively, they might want to display the object in its real size on a 1:1 scale.

2.2. Interaction with virtual 3D objects

Gestures are recognized as a significant modality of expression and communication. They are considered fundamental and innate kinesic components, comprising body postures, movements, and expressions that convey information that aligns with our discourse (Müller, 2017). During AR experiences mediated by HMD, researchers have investigated gestures that enable users to explore virtual objects in the most natural way possible, combining the intuitiveness of exploring physical objects with the additional features enabled by AR (Ortega et al., 2017). This involves combining gestures that are employed to interact with physical objects and exploiting the interaction metaphors used with more traditional user interfaces, e.g., zooming on a touch-screen interface (Orso et al., 2021; Hertel et al., 2021). This stands in stark contrast to traditional online shopping, where interaction is limited to scrolling and clicking, offering no direct manipulation of products (Barhorst et al., 2021). However, identifying the most natural interaction can become a complex process. This complexity arises from the variability of our interaction with objects, which largely depends on the context, consequently demanding an in-depth understanding of how we interact with different physical objects in various situations in our daily lives (Kang et al., 2020).

Pham and colleagues pointed out that participants involved in a laboratory experiment tended to interact with virtual objects taking into account their physical features, including size (Pham et al., 2018). They appeared to be influenced by the affordances of objects, adjusting their gestures in response to variations in object size, distance, and scene size. As an example, the size of the virtual object has an impact on the number of hands used to manipulate it. Smaller-size objects are typically grasped with a few fingers, whereas larger-size objects are grasped with one hand until they reach a size that requires the use of both arms as if the virtual object was perceived to be heavier. Similarly, the distance between the user and the object affects the type of gesture used: participants tend to use proximal gestures and appear to touch small-size objects, while larger-size objects are selected from distance using distal gestures. Other studies (Plank et al., 2017; Tarre et al., 2018; Orso, et al., 2021) suggested that users tend to favour wider actions when interacting with larger objects as opposed to smaller ones, even when performing the same action, and that users tend to import and exploit the interaction metaphors they already know. These findings suggest that our interaction with virtual objects is influenced by features of their physical twins and that our behaviour when interacting with virtual objects is modelled after our behaviour when interacting with their physical counterparts (Ortega et al., 2017; Pham et al., 2018).

The manipulation of virtual objects has also been investigated in immersive VR environments. Several studies have examined whether the size of virtual objects impacts the mid-air manipulation process. Findings indicated that the performance of manipulation tasks decreases significantly if virtual objects are too small or too large (Gloumeau et al., 2021; Viola et al., 2022) and that the time required to select small objects is twice as long as the time needed for larger objects (Wang et al., 2021). This leads to a less natural and more challenging interaction, considering both virtual and augmented contexts (Englmeier et al., 2020; He and Yang, 2014).

3. The study

The present study aims to explore whether the size of virtual objects affects costumers' preference for manipulation modality in AR. We compare unconstrained object scaling with automatic object scaling via anchoring, which allows users to view the product at a 1:1 scale.

While free-hand extensive item manipulation (i.e., rotating, resizing, and exploding objects using hand gestures instead of controllers) offers a more immersive experience (Kangas et al., 2022), the success of mobile AR apps that automatically scale large products (e.g., furnishings) to match room dimensions (Ozturkcan, 2021) may suggest a potential preference of the users for this feature also when using AR head-mounted displays.

We hypothesize that the preference for one or the other method of manipulation may depend on the intrinsic characteristics of the object, i. e., the size. Specifically, when manipulating large-sized objects, we hypothesize that users find more attractive and efficient an "automatic object scaling by anchoring" interaction mode (H1). For small objects we expect users to prefer "unconstrained object scaling" interaction modalities (H2), which allows them to explore the object by touching and rotating it, as is the case with physical products. To sum up, we expect a higher perceived usability and user experience in the "unconstrained object scaling" condition when compared to the "automatic object scaling by anchoring" condition for small products. We hypothesize that perceived usability and user experience will be better in the "automatic object scaling by anchoring" condition than in the "unconstrained object scaling" condition, for what concerns large products.

3.1. Experimental design

A 2 (object manipulation modality) x 2 (size of the object) within-participants design was employed. The two levels of the first independent variable were "unconstrained object scaling" and "automatic object scaling by anchoring", while the two levels of the second independent variable were "small-sized products" and "large-sized products". The resulting four experimental conditions were the following (Fig. 1):

The concept of "scaling" refers to the geometric manipulation technique (Hertel et al., 2021) employed to reduce or enlarge the size of an interactive element (Spittle et al., 2023). The "unconstrained object scaling" allowed participants to interact with 3D virtual products (i.e., small-sized, and large-sized) through hand gestures, scaling objects without necessarily respecting their actual size. They could freely manipulate the products by pinching, moving, rotating, enlarging, and reducing them according to their preferences. Differently, the "automatic object scaling by anchoring" allowed participants to automatically scale the products (i.e., small-sized, and large-sized) to their effective size. Users could manipulate the objects by grabbing them using the pinch action and moving them to the sphere-shaped anchor points (present to the left of the exhibitor) which allowed viewing the product on a 1:1 scale.

3.2. Equipment and technical set-up

3.2.1. Mid-air gestures and anchoring feature

Participants were provided with Microsoft HoloLens 2nd generation smart glasses (Windows Holographic OS, SoC Qualcomm Snapdragon 850 2.95 GHz, custom-built Holographic Processing Unit 2.0, 4GB

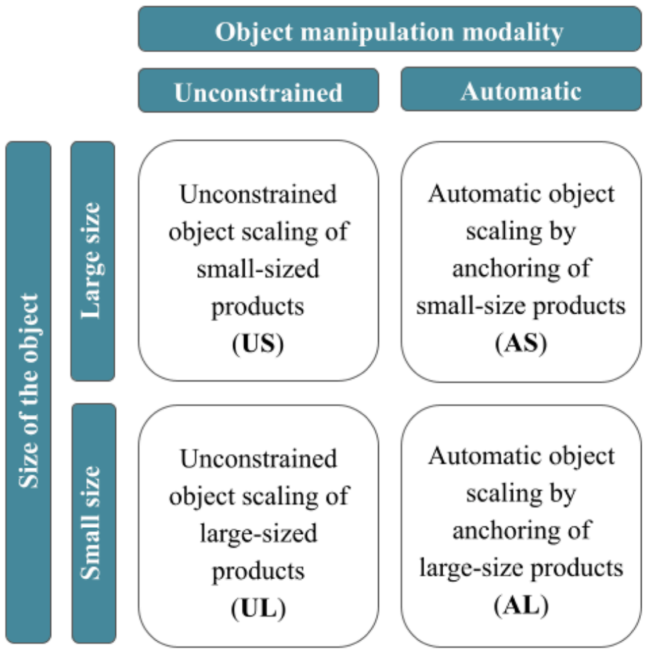

Fig. 1. The experimental design.

LPDDR4x system DRAM, see-through holographic lenses 2 K 3:2, 43° horizontal field of view, weight 56 g). As a fully untethered holographic computer, neither cables nor further devices were needed to execute the experiment. The display's field of view (FOV) angle was wide enough to allow users to visualize most of the virtual objects in their entirety at any distance. For larger objects, for example in the case of AL condition during the task, the anchoring points were placed far enough to prevent the model from clipping outside the field of view. The FOV of the sensors' cameras provided a much wider angle, allowing correct hand-tracking to all the gestures required for the interaction. Furthermore, despite the limited computational capabilities of the device, compared to a more standard desktop setup, the rendering frame rate was stable and did not cause any issue. This is quite likely due to the limited amount of objects being rendered in the AR layer.

The augmentation was created by developing an ad-hoc application able to run on the HoloLens 2, using the Unity Engine framework. The application provides several features, from the tracking and mapping of the surrounding environment to the interaction with the virtual objects including the manipulation gestures and the scaling modes used to create the different experimental conditions.

Participants interacted with the augmented objects using direct manipulation. The gestures performed by the participants are described in the table below (Table 1).

Table 1
Definitions of the gestures used in the experimental task.

Gesture	Definition
Grab	To fetch an object, the user places an open hand in front of the body, making a ray appear to indicate the direction of the interaction. By directing this ray at an object and closing the thumb and forefinger (pinch gesture), the object is grabbed. While maintaining the pinch, it is possible to move the object by moving the hand.
Object Scaling	To resize an object, the user performs the pinch gesture with both hands simultaneously. Widening or narrowing the position of the hands respectively enlarges or shrinks the object.
Object Rotation	By holding the object with a pinch gesture using one hand and rotating the wrist, the object can be rotated in any direction. Alternatively, the object can be rotated using two hands by performing the pinch gesture with both hands simultaneously and rotating them in the desired direction.

The anchoring feature has been specifically developed for this study. Two virtual sphere-shaped anchor points were positioned to the left of an exhibitor containing the virtual objects that the user was asked to manipulate (see Fig. 2). To scale the object using this feature, participants had to grab the object and move it in correspondence with the sphere-shaped anchor point. This made the object scale up to 1:1.

The 3D models of the objects have been downloaded from various online databases (i.e., Sketchfab, CGTrader, TurboSquid), under free or paid licenses, and were then modified using Blender to be compatible with the augmented reality application.

3.2.2. Virtual 3D products

The experiment involved two categories of 3D virtual objects: small-sized products and large-sized products. They consisted of two sub-categories of products: household appliances and furnishing elements, each including both large and small objects. Indeed, since our research question focuses on user preferences for manipulation modalities in AR based on product size, we selected two categories of products that include both large and small items and that are highly relevant to e-commerce, as evidenced by online sales statistics (Chizhevskiy, 2024) and the widespread use of AR applications in these sectors (e.g., IKEA Place). Finally, we excluded product categories where additional factors could significantly influence the user experience of object manipulation; for instance, while clothing is a major e-commerce category, the experience of handling garments is influenced not only by size but also by tactile aspects such as fabric texture and consistency (Gatter et al., 2022).

Both sub-categories of products (household appliances and furnishing elements) allowed participants to interact with different products under all experimental conditions. Small products included clocks, lamps, lanterns, and vases, for furnishing elements, and boilers, coffee machines, planetary mixers, and toasters, for household appliances. Large products comprised armchairs, chairs, shelves, and tables, for furnishing pieces and washing machines, smart TVs, fridges, and ovens, for appliances. For each product in the list, two different models have been proposed, for a total of 32 different virtual objects. All the products were located in a physical exhibitor, as depicted in Fig. 3.

3.2.3. Setting and physical exhibitor

The experiment took place in a laboratory located in the local university campus with constant artificial neutral lighting. The field of action was about 3 × 3 m, whereby participants were free to walk and interact with the stimuli. The 3D virtual objects were presented in a physical exhibitor composed of 16 compartments. Virtual objects were placed only on the upper half of the shelf, to be equally easily visible and reachable for participants (Fig. 3). Using the Vuforia engine tracking features and the spatial mapping features provided by the Hololens 2 development kit (MRTK), the application running on the headset, was able to correctly locate the physical exhibitor in the environment and

Fig. 2. Anchoring feature: the two sphere-shaped anchor points were located to the left of the exhibitor (participats' POV).

Fig. 3. Physical exhibitor with the 3D virtual products exposed (participants' POV). Small furnishing objects are displayed on the left, while large furnishing objects are displayed on the right. The virtual shopping cart is visible in the left image.

permanently store its position as a reference point to display all the 3D virtual objects inside it.

Virtual products have been resized all to the same size to fit in a 20-cm cube and randomly placed in the 8 exhibitor compartments most visible to users. On the right of the physical exhibitor, a virtual shopping cart was located. The two sphere-shaped anchor points were located on the left.

The image below (Fig. 4) illustrates the representation of the experimental setup during a participant's interaction with a virtual product, showing the physical exhibitor, the 3D virtual products, and the virtual shopping cart within the AR environment.

3.3. *Experimental task and procedure*

The experiment was designed in accordance with the Declaration of Helsinki and approved by the local ethics committee (Board of the Human Inspired Technology Research Centre, University of Padova).

The experimental procedure lasted approximately 60 min and consisted of five phases: (1) pre-experimental questionnaire, (2) familiarization with HoloLens HMD, (3) experimental training session, (4) experimental phase (5) post-experimental questionnaire.

3.3.1. *Pre-experimental questionnaire*

After providing written informed consent, participants completed a questionnaire collecting sociodemographic data (gender, age, educational level) and questions about previous experiences with AR HMDs and, specifically, HoloLens (see Section 3.4.1 for more detail).

Fig. 4. Representation of experimental set up that shows the unconstrained object scaling with large-sized objects condition (UL).

3.3.2. *Familiarization with hololens HMD*

This session was meant to allow participants to familiarize themselves with the AR technology and with the HoloLens 2 gestures. Once the headset was worn, the participant was asked to read the text instruction, complemented with video clips, illustrating the gestures to be performed to manipulate virtual objects. Subsequently, the participants were instructed to perform the gestures and interact with two neutral 3D objects (i.e., a pyramid and a cube) through 8 tasks provided verbally by the experimenter (e.g., "*Now I ask you to grab and release the white object at least three times, using the pinch action*"). This phase lasted a maximum of 10 min.

3.3.3. *Training session*

The training session was aimed at making participants learn the two object manipulation modalities ("unconstrained object scaling" and "automatic object scaling by anchoring"). In this session, the tasks to be performed were similar to those of the experimental phase. The participant was invited to stand in front of the exhibitor, which displayed a series of 3D neutral objects, and to perform 8 tasks verbally provided by the experimenter (e.g., "*Now I ask you to extract the red ball and enlarge it so that it has a diameter of about one meter, then I ask you to make it smaller and put it back in its place on the shelf.*"; "*Now take the blue cube out of the shelf and place it on one of the anchors so that it enlarges to a 1:1 scale*"). The researcher monitored the participants from a desktop computer so as not to interfere with their actions and assigned a score to each task on a previously created *ad hoc* observation grid to assess their performance. Only participants who completed the pre-training phase in a maximum of 10 min and with a success rate of 100 % were eligible to take part in the experiment. If participants did not meet such criteria they were thanked and dismissed.

3.3.4. *Experimental phase*

The experimental phase consisted of four experimental blocks, one per experimental condition: UL (block 1), US (block 2), AL (block 3), and AS (block 4). The order of presentation of the four experimental conditions was randomized.

During the experimental task, to help participants better contextualize the shopping experience, they were introduced to purchase scenarios. An example of a purchase scenario is the following: "*You have been asked to buy a new coffee machine for the office. Your company is particularly sensitive to environmental issues, so great care is always taken in making environmentally friendly choices. Identify the coffee machine that allows you to use both compostable pods and coffee powder and thus would not pollute. Then, put it in the shopping cart to buy it*". The scenarios were designed to motivate participants to search for and read a label that was placed on each object describing its characteristics, and as a result, to manipulate the object itself. Specifically, the task required them to explore two products (among the 8 positioned on the shelf) at a time (e.g., the two coffee machines) and purchase the one that met the requirements indicated by the scenario (e.g., allow to use compostable pods and coffee powder). The participants had to take the two products off the shelf and explore them carefully, comparing their labels, to buy the correct product. According to the experimental condition, participants were told how to interact with objects, either using unconstrained object scaling manipulation ("*grasp the two target objects, pull them off the shelf, and manipulate them freely by pinching, moving, rotating, enlarging, and reducing them according to your preferences*") or automatic scaling by anchoring ("*grasp the two target objects, pull them off the shelf, and move them to the sphere-shaped anchor points, which allows you to view the product on a 1:1 scale*"), see Fig. 5. They had no limit of time and products were not priced. Once they decided the product to purchase, they had to put it in the shopping cart and put back the unselected product on the shelf. Participants were presented with 3 different scenarios for each experimental condition, for a total of 12 scenarios.

After each experimental session, participants filled in a set of questionnaires to measure their experience with object manipulation and customer satisfaction with the shopping experience (for details see Section 3.4.1).

3.3.5. Post-experimental questionnaire

At the end of the experimental phase, questionnaires were administered to investigate overall user preferences in object manipulation (for details see Section 3.4.1).

3.4. Collected measures

In addition to the self-reported data collected through questionnaires, we also gathered behavioural data while participants interacted with the products. In the following section, the collected behavioural data and the self-report measures used are described.

3.4.1. Behavioural data

Behavioural data were automatically saved as a data-log file on the HoloLens internal storage (64 GB Universal Flash Storage 2.1), and then employed to compute the following metrics.

3.4.1.1. Purchasing success. It is the percentage of products correctly purchased according to the task scenario. This was used as a measure of task accuracy.

3.4.1.2. Time to complete the experimental session. We measured the total execution times of each experimental session (start: objects loading; end: placement of the last 3D virtual object in the shopping cart). This parameter reflects the time invested in purchasing.

3.4.1.3. Number of manipulations. The number of manipulations performed by the participant was tracked for each object, with each manipulation starting when the object was grabbed and ending when the object was released. This metric was used as a proxy of participants to explore and interact with products.

3.4.1.4. Duration of manipulations. The duration of manipulations (in seconds) performed by the participant was tracked for each object and indicated the time spent interacting with the object.

3.4.2. Self-report measures

Self-reported data were collected through the use of Qualtrics XM software (Qualtrics, 2020).

3.4.2.1. Socio-demographic data. In the pre-experimental phase, participants were asked about their age, gender, educational level, and prior experiences with AR HMD, including their familiarity with the HoloLens 2 headset, to gain insights into their backgrounds.

3.4.2.2. User eXperience (UX) with object manipulation. UX with the modality of manipulation of 3D virtual objects was evaluated through the User Experience Questionnaire (UEQ; Laugwitz et al., 2008), which was administered at the end of each experimental session. It includes 26 items made up of pairs of opposite adjectives (e.g., "*impractical – practical*", "*boring – exciting*"), with a response scale of 7 points. UEQ measures both pragmatic and hedonic components of the user experience according to Hassenzahl's model (Hassenzahl, 2010), providing a score for 6 different dimensions: *Attractiveness* (overall impression of the manipulation modality), *Perspicuity* (the extent to which it is easy to get familiar and learn the manipulation modality), *Efficiency* (users can solve the task without unnecessary effort), *Dependability* (the extent to which users feel in control of the interaction), *Stimulation* (indicates whether the manipulation modality is exciting and motivating), *Novelty* (refers to whether the manipulation modality is innovative and creative; Schrepp et al., 2014). *Attractiveness* is a pure valence dimension; *Perspicuity, Efficiency,* and *Dependability* are pragmatic quality aspects (goal-directed), while *Stimulation* and *Novelty* are hedonic quality aspects (non-goal-directed).

3.4.2.3. Customer satisfaction. To evaluate customer satisfaction related to the shopping experience several aspects were investigated, including *overall satisfaction* with the shopping experience, *desire to stay, engagement, repatronage intention.* The *overall satisfaction* was evaluated through one item ("*Overall I am satisfied with my experience in the virtual store*", 5-point Likert scale), adapted from Poushneh & Vasquez-Parraga (2017) and Taylor & Baker (1994). *Desire to stay* is an affective state of attraction to the environment that motivates the customer to remain in the environment for an extended period of time (Wakefield and Blodgett, 1994). It refers to the degree to which customers feel comfortable in the physical space and atmosphere of the service setting. To measure the degree to which customers feel engaged in the shop, we adapted one item from Wakefield & Blodgett (1994) on a 5-point Likert scale ("*I enjoyed spending time in this store*"). The level of *engagement* during the contextual exposures was evaluated in terms of presence "*I felt like in a physical store*", on a 7-point Likert scale, as suggested by Andersen et al., 2019. *Repatronage intention* or purchase intention is a concept that refers to a customer's likelihood of purchasing a product or taking benefit of the service in the future (Oliver and Swan, 1989). We evaluated the

Fig. 5. Example of exploring a small product through the "unconstrained object scaling" (left) and an example of exploring a large product through the "automatic object scaling by anchor" modality (right).

intention to purchase again in the AR shop through 4 items adapted from Oliver and Swan (1989). Items are provided by a semantic differential on a series of bipolar adjectives placed at the extremes of a 7-point scale ("*In the future, when technology allows it, my shopping in this type of virtual store will be… not at all frequent – very frequent; unlikely – plausible; unlikely – very likely; impossible – very possible*").

3.4.2.4. Overall user preferences. Once the experimental phase was concluded, the overall users' preferences concerning the manipulation modality were assessed. A post-experimental questionnaire was devised investigating *ease of use, effectiveness, utility,* and *pleasantness* through 8 items created *ad hoc* (4 related to large objects and 4 related to small objects). The items had the form of a semantic differential, i.e., the two different manipulations were placed at the extremes of a 7-point scale to understand users' preferences.

3.5. Participants

A total of 40 participants volunteered to take part in the study. All participants provided informed consent before engaging in the study. They did not receive any compensation for participation. The inclusion criteria were: (a) being between the ages of 18 and 40, (b) having an excellent comprehension of the Italian language (c) having no significant vision problems and not using glasses or contact lenses; (d) not being under psychopharmacological treatments.

The sample comprised 20 females and 20 males, with an average age of 26 years, (SD = 3.10, range 21–33), and an average education level of 15.65 years (SD = 2.70, min = 8, max = 21). An a priori power analysis conducted using G*Power (Faul et al., 2007) indicated that a sample size of 40 is sufficiently large to achieve a statistical power (1-β) = 0.95 in a repeated-measures within factor design involving 4 experimental conditions, given a significance level $\alpha = 0.05$ and a medium effect size (0.25).

Regarding their previous experiences with AR, most of the participants ($N = 29$, 72.50 %) had never used an AR headset, only 5 participants had used it once (12.50 %), 5 participants a few times (12.50 %), and just one participant declared using it often (2.50 %). Among the 11 participants who had previous experience with augmented reality headsets, 1 used the HoloLens 2 headset often, 1 used it occasionally, and 4 participants used it only once. The remaining 5 participants were unsure about the specific type of headset they had used.

4. Analysis and results

4.1. Data analysis

Data analysis was run in RStudio (RStudio Team, 2020). Shapiro-Wilk tests highlighted the non-normal distribution of the data. Therefore, non-parametric analyses were performed.

Data from the questionnaires filled at the end of each experimental session were analyzed as follows: a series of Wilcoxon tests were conducted to determine if there were any effects on the measured dependent variables for the size of the object, the object manipulation modality, and the interaction between the two variables (object size - object manipulation modality). The *p*-values obtained from the analyses were adjusted with the application of the B.H. method (Benjamini and Hochberg, 1995). The following is a detailed explanation of the data analyzed:

- Object size variable. The scores given by participants to rate their experience of manipulating small objects (mean of scores related to data obtained from unconstrained object scaling and automatic scaling of small objects) were compared with the scores given when manipulating large objects (mean of scores related to unconstrained object scaling and automatic scaling of large objects).
- Object manipulation variable. The scores obtained when using the unconstrained scaling of the object (mean of scores related to data obtained from unconstrained scaling of small objects and large objects) were compared with the scores obtained when using the automatic scaling (mean of scores related to automatic manipulation of large objects and from automatic manipulation of small objects).
- Interaction (object size x object manipulation). One delta score was calculated by subtracting the data obtained during the unconstrained scaling of large objects from the data obtained during the automatic scaling of large objects. The other delta was calculated by subtracting the data obtained during the unconstrained scaling of small objects from the automatic scaling of small objects.

When statistically significant results emerged, a series of post-hoc tests were performed with the application of B.H. correction for multiple comparisons. Comparisons with Wilcoxon signed-rank tests for paired samples (B.H. correction) were conducted.

For each of the dimensions investigated through the post-experimental questionnaire, a series of one-sample Wilcoxon tests (B.H. correction) were run against the median point of the response scale to test whether the opinions provided by the participants were positive or negative.

4.2. Results

4.2.1. Behavioural measures

4.2.1.1. Purchasing success. Fisher's exact test was conducted to examine the association between the experimental condition and the correct purchase of products. The results showed no significant association ($p = 1.00$), indicating that experimental conditions did not have a significant impact on the likelihood of choosing the correct product. As shown in Table 2, users purchased the correct products in all the different augmented reality shops.

4.2.1.2. Time invested in purchasing. Fig. 6 shows the time users spent shopping in the different experimental sessions. Wilcoxon's tests (B.H. corrections) showed that there was no statistically significant difference in purchase time considering both object size ($V = 342.00$, $z = -0.91$, $p = 0.36$) and manipulation ($V = 258.00$, $z = -2.04$, $p = 0.12$) and the interaction between the two variables ($V = 313.00$, $z = -1.30$, $p = 0.30$). Thus, it turns out that users spent the same amount of time exploring the objects and making the purchase in the different sessions.

4.2.1.3. Number and duration of manipulations. The analysis investigated whether there was an effect of the experimental conditions on the numbers and durations of manipulations. Results are reported in Table 3.

A series of post-hoc Wilcoxon tests was performed. It was found that the number of manipulations performed was higher when the manipulation was unconstrained. Particularly, during unconstrained manipulation ($V = 648.50$, $z = 3.60$, $p < 0.001$) the participants manipulated the larger objects (Mdn = 7.08, $M = 9.22$, SD = 5.45) more than the smaller ones (Mdn = 6.58, $M = 6.69$, SD = 2.47).

Similar results emerged about the time spent to manipulate products: users manipulated objects for a longer time when they had

Table 2
Percentage of correct purchase of products.

Purchase of products		
Object Size - Object Manipulation	correct (%)	error (%)
Large objects - Automatic scaling	100.00 %	0.00 %
Large objects - Unconstrained scaling	99.17 %	0.83 %
Small objects - Automatic scaling	98.33 %	1.67 %
Small objects - Unconstrained scaling	100.00 %	0.00 %

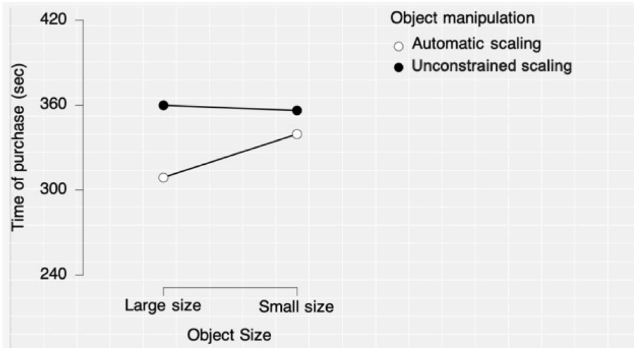

Fig. 6. Time invested in purchasing under different conditions.

Table 3
Results of Wilcoxon tests on number and duration of manipulations; (*p(B.H.) < 0.05).

Number and duration of manipulations				
Dependent variable	Independent variable	V	z	*p* (B.H.)
Number of manipulation*	Object Size	666.00	3.85	< 0.001
	Object Manipulation	45.00	4.91	< 0.001
	Object Size x Object Manipulation	207.00	2.32	0.02
Duration of manipulation*	Object Size	657.00	3.32	< 0.001
	Object Manipulation	51.00	4.83	< 0.001
	Object Size x Object Manipulation	805.00	5.31	< 0.001

unconstrained manipulation. In addition, they spent more time manipulating the larger objects (Mdn = 18.98, M = 25.71, SD = 17.46) compared to the smaller ones (Mdn = 18.73, M = 18.97, SD = 6.64), see Table 4.

4.2.2. *UX with object manipulation*

The UX with each object manipulation modality (UL, US, AL, AS) was assessed through the UEQ at the end of each experimental session. Significant differences between the four experimental conditions emerged in the following UEQ dimensions: *Attractiveness, Perspicuity, Efficiency* and *Stimulation*. Table 5 reports the results of the Wilcoxon tests for each UEQ dimension.

The post-hoc analyses showed that it is more attractive ($V = 461$, $p = 0.001$) to manipulate large objects (Mdn = 2.00, M = 1.76, SD = 0.98) than small objects (Mdn = 1.17, M = 0.97, SD = 1.19) by using the automatic scaling mode. It is more attractive ($V = 515.50$, $p < 0.01$) to manipulate large objects with automatic scaling (Mdn = 2.00, M = 1.76, SD = 0.98) than by unconstrained scaling (Mdn = 1.12, M = 1.21, SD = 1.00). Finally, it is more attractive to manipulate large objects with automatic scaling than small objects with unconstrained scaling ($V = 501.50$, $p = 0.01$). Greater perspicuity emerged ($V = 495.50$, $p < 0.001$) for manipulating large objects with automatic scaling (Mdn = 2.625, M = 2.28, SD = 0.79) than for manipulating objects of the same size with unconstrained scaling (Mdn = 1.75, M = 1.40, SD = 1.26), and then for small objects with both automatic ($V = 337.50$, $p = 0.02$; Mdn = 2.00, M = 1.83, SD = 0.94) and unconstrained scaling ($V = 425.00$, $p < 0.001$; Mdn = 1.62, M = 1.51, SD = 1.06). Small objects with automatic scaling (M = 1.83, SD = 0.94) have greater perspicuity than small ($V = 466$, $p < 0.05$; Mdn = 1.62, M = 1.51, SD = 1.06) and large objects ($V = 352.50$, $p < 0.05$; Mdn = 1.75, M = 1.40, SD = 1.26) unconstrained scaling. In addition, participants reported perceiving themselves as more efficient ($V = 434$, $p < 0.01$) when using the automatic manipulation with large objects (Mdn = 1.88, M = 1.91, SD = 0.90) than with small ones (Mdn = 1.25, M = 1.23, SD = 1.14). They reported more efficiency in manipulating large objects with automatic manipulation than by the unconstrained one both large ($V = 520.00$, $p < 0.001$; Mdn = 0.75, M = 0.92, SD = 1.19) and small ($V = 610$, $p < 0.001$; Mdn = 0.75, M = 0.89, SD = 1.08) objects. Although the stimulation dimension was significant in Wilcoxon's test for interaction (object manipulation x object size), no significance emerged from post hoc tests with B.H. corrections.

Table 4
Descriptive statistics of numbers and durations of manipulations (median, mean and standard deviation).

Number and duration of manipulation: descriptive statistics						
Object Size - Object Manipulation	Number of manipulations			Duration of manipulations		
	Mnd	M	SD	Mdn	M	SD
Large objects - Automatic scaling	3.42	4.31	3.14	9.27	11.10	6.83
Large objects - Unconstrained scaling	7.08	9.22	5.45	18.98	25.71	17.46
Small objects - Automatic scaling	3.08	3.30	1.12	9.31	10.10	3.13
Small objects - Unconstrained scaling	6.58	6.69	2.47	18.73	18.97	6.42

Table 5
Results of Wilcoxon tests on user experience questionnaire (UEQ).

User Experience Questionnaire				
Dimension	Independent variable	V	z	*p* (B.H.)
Attractiveness *	Object Size	518.00	2.91	0.01
	Object Manipulation	394.00	0.96	0.34
	Object Size x Object Manipulation	522.50	3.40	<0.01
Perspicuity *	Object Size	393.00	1.63	0.10
	Object Manipulation	467.00	2.90	0.01
	Object Size x Object Manipulation	447.00	1.79	0.10
Efficiency *	Object Size	540.50	3.26	<0.01
	Object Manipulation	568.00	2.86	0.01
	Object Size x Object Manipulation	483.00	1.98	0.04
Dependability	Object Size	382.50	0.47	0.64
	Object Manipulation	451.50	1.17	0.37
	Object Size x Object Manipulation	450.00	1.15	0.37
Stimulation *	Object Size	323.50	1.11	0.40
	Object Manipulation	303.50	0.41	0.69
	Object Size x Object Manipulation	389.50	3.23	<0.01
Novelty	Object Size	274.00	−0.67	0.51
	Object Manipulation	278.00	−0.86	0.51
	Object Size x Object Manipulation	357.50	0.70	0.51

* p (B.H.) < 0.05.

4.2.3. *Customer satisfaction*

Customer satisfaction with the shopping experience was assessed through a questionnaire that was administered at the end of each experimental session and investigated the following dimensions: *overall satisfaction, desire to stay, engagement, repatronage intention.* Table 6 reports the results of the Wilcoxon tests for each dimension.

Post-hoc results showed that participants felt less engaged ($V = 208.50$, $p < 0.01$) when the manipulation of large objects was unconstrained (Mdn = 2.00, M = 2.50, SD = 0.93) than automatic (Mdn = 3.00, M = 3.08, SD = 1.02).

Moreover, they reported a higher level of repatronage ($V = 87.00$, $p = 0.04$) for unconstrained manipulation of small objects (Mdn = 5.75, M = 5.44, SD = 1.13) than for large objects (Mdn = 5.00, M = 5.09, SD =

Table 6
Results of Wilcoxon tests on customer satisfaction questionnaire.

Customer satisfaction questionnaire				
Dimension	Indipendent variable	V	z	p (B. H.)
Overall Satisfaction	Object Size	122.50	1.11	0.25
	Object Manipulation	168.50	1.84	0.09
	Object Size x Object Manipulation	181.00	2.28	0.06
Desire to stay	Object Size	193.00	1.67	0.12
	Object Manipulation	204.00	1.12	0.26
	Object Size x Object Manipulation	193.50	1.69	0.12
Engagement*	Object Size	221.00	0.40	0.67
	Object Manipulation	320.00	2.22	0.03
	Object Size x Object Manipulation	334.00	2.52	0.03
Repatronage intention*	Object Size	199.00	-0.09	0.94
	Object Manipulation	256.00	-0.15	0.94
	Object Size x Object Manipulation	418.00	3.33	< 0.01

* p(B.H.) < 0.05.

1.15). A higher level of repatronage ($V = 287$, $p = 0.03$) emerged for large objects with automatic manipulation (Mdn = 5.50 $M = 5.48$; SD 1.02) than with unconstrained manipulation (Mdn = 5.00 M = 5.09 SD = 1.15).

From Wilcoxon tests in comparison with the median of the response scale (Mdn = 3), users reported being overall satisfied in all 4 conditions: automatic manipulation of large objects ($V = 630$, $p < 0.001$; Mdn = 4.00, $M = 4.12$, SD = 0.60), automatic manipulation of small objects ($V = 604.50$, $p < 0.01$; Mdn = 4.00, $M = 3.78$, SD = 0.89), unconstrained manipulation of large objects $V = 481.50$, $p < 0.01$; Mdn = 4.00, $M = 4.12$, SD = 0.60), and unconstrained manipulation of small objects ($V = 606.00$, $p < 0.01$; Mdn = 4.00, $M = 4.01$, SD = 0.67). The same was observed for the desire to stay in the AR shop for all experimental conditions: automatic manipulation of large objects ($V = 652.00$, $p < 0.01$; Mdn = 4.00, $M = 4.01$, SD = 0.67), automatic manipulation of small objects ($V = 570.50$, $p < 0.01$; Mdn = 4.00, $M = 3.78$, SD = 0.70), unconstrained manipulation of large objects ($V = 466.50$, $p < 0.01$; Mdn = 4.00, $M = 3.75$, SD = 0.90), and unconstrained manipulation of small objects ($V = 536.00$, $p < 0.01$; Mdn = 4.00, $M = 3.83$, SD = 0.84).

4.2.4. *Overall user preferences*

Data analysis on the post-experimental questionnaire, which included questions about *ease of use, effectiveness, utility,* and *pleasantness* of each manipulation modality, revealed that users perceive it easier to manipulate a large object by using the automatic manipulation ($V = 725.50$, $p < 0.001$; Mdn = 7.00, $M = 5.98$, SD = 1.64), while for small objects they perceive as easier using the unconstrained manipulation mode ($V = 158.00$, $p < 0.01$; Mdn = 2.00, $M = 2.85$, SD = 2.10). Participants reported that it is more pleasant to manipulate a large object through automatic manipulation ($V = 596.00$, $p < 0.001$; Mdn = 7.00, $M = 5.53$, SD = 2.04), while a small object through the unconstrained one ($V = 120.00$, $p < 0.01$; Mdn = 2.00, $M = 2.90$, SD = 1.92). Greater effectiveness emerged for large objects using the automatic manipulation ($V = 691.50$, $p < 0.001$; Mdn = 7.00, $M = 5.85$, SD = 1.79) while for small objects the unconstrained one ($V = 183.50$, $p < 0.01$; Mdn = 2.00, $M = 2.83$, $M = 2.18$). Finally, users perceive it as more useful to use automatic manipulation for large objects ($V = 388.50$, $p < 0.01$; Mdn = 5.00, $M = 4.98$, SD = 1.98) and unconstrained manipulation for small objects ($V = 89.00$, $p < 0.01$; Mdn = 3.00, $M = 3.05$, SD = 1.92).

5. Discussion

The advent of AR technologies has opened a new vista in the retail sector, transcending traditional online shopping experiences by embedding a layer of interactivity and immersion (Dargan et al., 2023). The usability of AR e-commerce platforms is crucial for encouraging user adoption and engagement (Tatzgern et al., 2016). This involves ensuring that virtual representations are manipulable and realistic, allowing users to explore products easily and as they would in the physical world (Poretski et al., 2021). For example, when designing AR shopping experiences, it is essential to consider the specific characteristics of the products that users will interact with (Pham et al., 2018; Tatzgern et al., 2013).

The present work investigated modalities to interact with 3D virtual products of different sizes during an AR shopping experience focusing on customer experience and satisfaction. In one case, virtual 3D objects of large and small sizes could be explored through hand gestures in their real size (1:1 scale). On the other, the potential of AR to enlarge or shrink products at the user's will, without respecting the scale of the physical world, was exploited. Participants were presented with a series of purchasing scenarios and asked to explore the products and purchase the ones that met the scenarios' requirements. The scenarios involved exploring large (e.g., oven, armchair) or small (e.g., coffee maker, lamp) household appliances and home goods. Thus, participants explored large objects with automatic manipulation, large objects with unconstrained manipulation, small objects with automatic manipulation, and small objects with unconstrained manipulation. During the AR experience, participants successfully purchased products under all conditions. Users made the purchases demanded by the scenarios with high accuracy (98 % to 100 %) with no difference in their performance.

Results highlighted how users reported an overall positive experience while manipulating the virtual products, in line with previous studies (Kang et al., 2020). However, significant differences emerged between different object sizes and manipulation modes. Consistently with our hypothesis, manipulating large objects with the automatic resize by anchoring is considered more attractive than in the unconstrained manipulation modality. Also, the automatic modality was more attractive for large objects compared to small ones. In terms of efficiency, manipulating large objects in the automatic modality was easier and required less effort as compared to unconstrained modality and small object manipulations (in both automatic and unconstrained modalities). Furthermore, the automatic modality was found to be more perspicuous as compared to the unconstrained one. It was easier for participants to learn how to manipulate virtual objects in the automatic resize by anchoring manipulation regardless of the size of the objects, as compared with the unconstrained manipulation modality both with large and small objects. Thus, manipulating large objects in automatic modality showed better usability; considering object size, automatic manipulation is considered more perspicuous with large products. The results from the UX questionnaire are in line with those emerging from the post-experimental questionnaire related to the overall manipulation preferences. For large products, users considered more effective, easy, useful, and pleasant, the automatic manipulation modality, in line with our first hypothesis (H1). These results are in line with the seamless experiences reported in AR applications like IKEA's "Place" and Amazon's "View in your room" feature (Ozturkcan, 2021; Romano et al., 2021). The preference for automatic manipulation among users suggests a desire for a shopping experience that closely mimics the physical world's realism when evaluating larger items that require spatial accuracy for placement in one's environment.

Differently, for small products users considered more effective, easy, useful, and pleasant, the unconstrained manipulation modality, according to our second hypothesis (H2). It seems that users appreciate the ability to scrutinize fine details more closely, reflecting the need for a tactile-like experience in online shopping, as mentioned by Hilken and colleagues (2022).

Behavioural data showed that participants manipulate products more when it is possible to zoom them in and out according to their preferences. They manipulate larger objects with more gestures and for a longer time than smaller ones. It could therefore be hypothesized that more interaction with the large product is required to find all necessary information and view the details of products. Nonetheless, the time spent to complete product purchases successfully did not differ significantly among all the conditions, which means that the time to purchase products is not affected by the size of objects or manipulation modalities.

As concern customer satisfaction, results suggested that in all conditions users were overall satisfied with the experience in the augmented store, and they enjoyed spending time in it, corroborating the positive effects noted by Dargan and colleagues (2023). However, participants expressed that in a future shopping experience, they would prefer an unconstrained exploration of small-sized products. Related to large-sized products, they have indicated a preference for a guided interaction, with automatic manipulation allowing exploration of the object in its actual physical dimensions. Congruently, participants felt less like they were in a physical store when they were asked to freely manipulate large-size products. To sum up, results suggest that changing the manipulation modality according to the size of the product affects the user experience in an AR shopping environment. Moreover, tailoring the interaction methods based on the nature of the product influences repatronage intention, contributing valuable insights for the enhancement of sales in augmented reality shops.

This study highlights evidence-based design implications for AR applications in retail and e-commerce. To enhance customer experience, the choice of object manipulation modality should be informed by the size of the virtual product, as this significantly influences UX, shopping satisfaction and user preferences. For large virtual products, such as furniture and appliances, implementing an automatic scaling modality that displays items at a 1:1 scale has been shown to benefit users. Automatic scaling with large objects allows users to focus on spatial evaluation rather than adjusting product dimensions, enabling consumers and retailers to optimize product fit evaluations. Conversely, for small virtual products like kitchen appliances and decorative objects, incorporating an unconstrained manipulation modality allows users to freely zoom, rotate, and inspect details. This hands-on exploration facilitates a more engaging purchasing experience and extends the exploration of the physical products that is typical of in-store shopping.

5.1. Limitations and future perspectives

Despite insightful, the findings of the present study come with limitations. Firstly, we have considered only two categories of products, i.e., household appliances and pieces of furniture. These items are characterized by a high utilitaristic value, in that they mainly serve a specific function. Different groups of products involving a closer interaction with the user once in use should be considered in future studies. For instance, accessories such as pieces of jewellery or suitcases, that contribute to define one's image. Additionally, both appliances and furniture are characterized by a low sensorial stimulation, because, also in their physical counterpart, they mainly activate the visual system (especially for the household appliances). In the future, it is important to study whether products that more strongly involve other sensory aspects (i.e., smell, taste) would benefit from different types of manipulations to enhance the shopping experience.

Moreover, the study was conducted in a laboratory setting and involves only quantitative data. While this choice was motivated by the willingness to carefully control the experimental conditions, it came at the cost of losing the naturalness and the complexity of the interaction typical of a genuine shopping environment. Additionally, it did not provide participants with the opportunity to directly report their experience. Subsequent research should be conducted in situ at retail locations to engage actual customers, whose purchasing motivation can provide more insight on the use and impact of AR in shopping contexts, and integrate qualitative research methods, such as interviews, to voice participants' opinions and thoughts.

Finally, the sample considered in this study was comprised of young adults with a homogenous background. Future studies should be extended to encompass user groups with more heterogeneous profiles. For instance, participants with diverse age and levels of expertise with AR systems should be involved, to investigate the extent to which these shopping systems are intuitive and inclusive.

6. Conclusions

The present study examined how object manipulation modality (automatic scaling vs. unconstrained manipulation) and object size (large vs. small) affect user experience (UX), customer satisfaction, and purchasing behaviour in AR shopping. Purchasing success and time spent shopping did not differ significantly across conditions. However, users performed more and longer manipulations with unconstrained manipulation, especially for large objects. UX ratings showed that automatic scaling of large objects was more attractive, efficient, and easy to get familiar with, while unconstrained manipulation was preferred for small objects. Customer satisfaction was high in all conditions, with greater engagement for large objects with automatic scaling and higher repatronage intentions for small objects with unconstrained manipulation.

Integrating AR across physical stores and online platforms creates a seamless shopping journey, bridging the gap between digital and in-store experiences. This paper suggests that providing different modalities of manipulation depending on the size of the 3D products to be purchased allows for enriching the shopping experience. Indeed, as our gestures adapt to the affordances of objects (Pham et al., 2018) and their sizes, it is appropriate to replicate what happens in the physical world in augmented reality environments as well.

This work extends knowledge about interactions with 3D objects (Ortega et al., 2017; Pham et al., 2018) during a shopping experience with augmented reality. Findings may help to inform the design of AR applications in the retail sector, with particular reference to 3D product manipulation techniques. According to the results of the present study, the following recommendations are given: (i) large 3D virtual products need a dimensional representation that is faithful to that of the physical product (1:1 scale); (ii) exploration of small 3D virtual products should include the ability to resize the object according to one's preferences.

By focusing on user-friendly interfaces and intuitive interactions, AR platforms can significantly enhance the online shopping experience, making it more immersive and informative. This increases the likelihood of purchase among consumers who are more inclined to pay for a product after engaging with it in a detailed, interactive manner (Kang et al., 2020).

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Ethics approval

The project was approved by the he local ethics committee (Board of the Human Inspired Technology Research Centre, University of Padova).

CRediT authorship contribution statement

Merylin Monaro: Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Alice Bettelli:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Giovanni Portello:** Writing – original draft, Investigation, Data curation, Conceptualization. **Leonardo Pierobon:** Writing – original draft, Software, Investigation. **Valeria Orso:** Writing – original draft, Supervision, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Alimamy, S., Gnoth, J., 2021. I want it my way! the effect of perceptions of personalization through augmented reality and online shopping on customer intentions to co-create value. Comput. Hum. Behav. 128, 107105. https://doi.org/10.1016/j.chb.2021.107105.

Andersen, I.N.S.K., Kraus, A.A., Ritz, C., Bredie, W.L.P., 2019. Desires for beverages and liking of skin care product odors in imaginative and immersive virtual reality beach contexts. Food Res. Int. 117, 10–18. https://doi.org/10.1016/j.foodres.2018.01.027.

Barhorst, J.B., McLean, G., Shah, E., Mack, R., 2021. Blending the real world and the virtual world: exploring the role of flow in augmented reality experiences. J. Bus. Res. 122, 423–436. https://doi.org/10.1016/j.jbusres.2020.08.041.

Barta, S., Gurrea, R., Flavián, C., 2023. How augmented reality increases engagement through its impact on risk and the decision process. Cyberpsychology Behav. Soc. Netw. 26 (3), 177–187. https://doi.org/10.1089/cyber.2022.0087.

Baytar, F., Chung, T., Shin, E., 2020. Evaluating garments in augmented reality when shopping online. J. Fash. Mark. Manag.: Int. J. https://doi.org/10.1108/jfmm-05-2018-0077 ahead-of-print(ahead-of-print).

Benjamini, Y., Hochberg, Y., 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. J. R. Stat. Soc.: B (Methodol.) 57 (1), 289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x.

Boboc, R.G., Gîrbacia, F., Butilă, E.V., 2020. The application of augmented reality in the automotive industry: a systematic literature review. Appl. Sci. 10 (12), 4259. https://doi.org/10.3390/app10124259.

Bowman, Doug A., McMahan, Ryan P., Ragan, Eric D., 2012. Questioning naturalism in 3D user interfaces. Commun. ACM 55 (9), 78–88. https://doi.org/10.1145/2330667.2330687 (September 2012).

Chen, Y., Wang, Q., Chen, H., Song, X., Tang, H., Tian, M., 2019. An overview of augmented reality technology. J. Phys.: Conf. Ser. 1237 (2), 022082. https://doi.org/10.1088/1742-6596/1237/2/022082.

Chizhevskiy, O., 2024. Amazon product categories. Nuoptima Insights. https://nuoptima.com/amazon-product-categories.

Dargan, S., Bansal, S., Kumar, M., Mittal, A., Kumar, K., 2023. Augmented Reality: a comprehensive review. Arch. Comput. Methods Eng. 30 (2), 1057–1080. https://doi.org/10.1007/s11831-022-09831-7.

Das, P., Zhu, M., McLaughlin, L., Bilgrami, Z., Milanaik, R., 2017. Augmented reality video games: new possibilities and implications for children and adolescents. Multimodal Technol. Interact. 1 (2), 8. https://doi.org/10.3390/mti1020008.

Englmeier, D., Dorner, J., Butz, A., & Hollerer, T. (2020). A tangible spherical proxy for object manipulation in augmented reality. *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 221–229. https://doi.org/10.1109/VR46266.2020.00041.

Farshid, M., Paschen, J., Eriksson, T., Kietzmann, J., 2018. Go boldly! Bus. Horiz. 61 (5), 657–663. https://doi.org/10.1016/j.bushor.2018.05.009.

Faul, F., Erdfelder, E., Lang, A.-G., Buchner, A., 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 39 (2), 175–191. https://doi.org/10.3758/BF03193146.

Fu'adi, D.K., Hidayanto, A.N., Inan, D.I., & Phusavat, K. (2021). The implementation of augmented reality in E-commerce customization: a systematic literature review. *2021 13th International Conference on Information & Communication Technology and System (ICTS)*, 12–17. https://doi.org/10.1109/ICTS52701.2021.9608322.

Gabriel, A., Ajriya, A.D., Fahmi, C.Z.N., Handayani, P.W., 2023. The influence of augmented reality on E-commerce: a case study on fashion and beauty products. Cogent Bus. Manag. 10 (2). https://doi.org/10.1080/23311975.2023.2208716.

Gatter, S., Hüttl-Maack, V., Rauschnabel, P.A., 2022. Can augmented reality satisfy consumers' need for touch? Psychol. Mark. 39 (3), 508–523. https://doi.org/10.1002/mar.21618.

Gloumeau, P.C., Stuerzlinger, W., Han, J., 2021. PinNPivot: object manipulation using pins in immersive virtual environments. IEEE Trans. Vis. Comput. Graph. 27 (4), 2488–2494. https://doi.org/10.1109/TVCG.2020.2987834.

Graziano, T., Privitera, D., 2020. Cultural heritage, tourist attractiveness and augmented reality: insights from Italy. J. Herit. Tour. 15 (6), 666–679. https://doi.org/10.1080/1743873X.2020.1719116.

Guo, C., Zhang, X., 2024. The impact of AR online shopping experience on customer purchase intention: an empirical study based on the TAM model. PLoS. One 19 (8). https://doi.org/10.1371/journal.pone.0309468 e0309468–e0309468.

Hassenzahl, M., 2010. Experience design. technology for all the right reasons. Springer International Publishing. https://doi.org/10.1007/978-3-031-02191-6.

He, Z., & Yang, X. (2014). Hand-based interaction for object manipulation with augmented reality glasses. *Proceedings of the 13th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry*, 227–230. https://doi.org/10.1145/2670473.2670505.

Heinrich, F., Bornemann, K., Polenz, L., Lawonn, K., Hansen, C., 2023. Clutch & grasp: activation gestures and grip styles for device-based interaction in medical spatial augmented reality. Int. J. Hum. Comput. Stud. 180, 103117. https://doi.org/10.1016/j.ijhcs.2023.103117.

Hertel, J., Karaosmanoglu, S., Schmidt, S., Braker, J., Semmann, M., & Steinicke, F. (2021). A taxonomy of interaction techniques for immersive augmented reality based on an iterative literature review. *2021 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 431–440. https://doi.org/10.1109/ISMAR52148.2021.00060.

Hietanen, A., Pieters, R., Lanz, M., Latokartano, J., Kämäräinen, J.-K., 2020. AR-based interaction for human-robot collaborative manufacturing. Robot. Comput. Integr. Manuf. 63, 101891. https://doi.org/10.1016/j.rcim.2019.101891.

Hilken, T., Chylinski, M., Keeling, D.I., Heller, J., Ruyter, K., Mahr, D., 2022. How to strategically choose or combine augmented and virtual reality for improved online experiential retailing. Psychol. Mark. 39 (3), 495–507. https://doi.org/10.1002/mar.21600.

Jussila, I., Tarkiainen, A., Sarstedt, M., Hair, J.F., 2015. Individual psychological ownership: concepts, evidence, and implications for research in marketing. J. Mark. Theory Pract. 23 (2). https://doi.org/10.1080/10696679.2015.1002330.

Kang, H.J., Shin, J., & Ponto, K. (2020). A comparative analysis of 3D user interaction: how to move virtual objects in mixed reality. *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 275–284. https://doi.org/10.1109/VR46266.2020.00047.

Kangas, J., Kumar, S.K., Mehtonen, H., Järnstedt, J., Raisamo, R., 2022. Trade-off between task accuracy, task completion time and naturalness for direct object manipulation in virtual reality. Multimodal Technol. Interact. 6 (1), 6. https://doi.org/10.3390/mti6010006.

Kljun, M., Geroimenko, V., Čopič Pucihar, K., 2020. Augment. Real. Educ.: Curr. Status Adv. Field 3–21. https://doi.org/10.1007/978-3-030-42156-4_1.

Laugwitz, B., Held, T., Schrepp, M., 2008. Constr. Eval. User Exp. Quest. 63–76. https://doi.org/10.1007/978-3-540-89350-9_6.

Mendes, D., Caputo, F.M., Giachetti, A., Ferreira, A., Jorge, J., 2019. A survey on 3D virtual object manipulation: from the desktop to immersive virtual environments. Comput. Graph. Forum 38, 21–45. https://doi.org/10.1111/cgf.13390.

Müller, C., 2017. How recurrent gestures mean. Gesture 16 (2), 277–304. https://doi.org/10.1075/gest.16.2.05mul.

Oliver, R.L., Swan, J.E., 1989. Consumer Perceptions of interpersonal equity and satisfaction in transactions: a field survey approach. J. Mark. 53 (2), 21. https://doi.org/10.2307/1251411.

Orso, V., Bettelli, A., Zamboni, L., Gamberini, L., 2021. How would do that? An agile elicitation technique to explore users' Spontaneous gestural commands. In: Ambient assisted living: italian forum 2019, 10. Springer International Publishing, pp. 139–152.

Orso, V., Portello, G., Pierobon, L., Bettelli, A., & Monaro, Merylin Gamberini, L. (2022). Rethinking the shopping experience: a qualitative explorative study on 3D web and AR for displaying and selling goods. *Proceedings of the IHCI + GET 2022 Proceedings*, 142–148.

Ortega, F.R., Galvan, A., Tarre, K., Barreto, A., Rishe, N., Bernal, J., Balcazar, R., & Thomas, J.-L. (2017). Gesture elicitation for 3D travel via multi-touch and mid-air systems for procedurally generated pseudo-universe. *2017 IEEE Symposium on 3D User Interfaces (3DUI)*, 144–153. https://doi.org/10.1109/3DUI.2017.7893331.

Ozok, A.A., & Komlodi, A. (2007). Do looks really matter? The effect of 3-dimensional product representations on the customers' buying decision in electronic commerce. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 51(17), 1050–1052. https://doi.org/10.1177/154193120705101711.

Ozturkcan, S., 2021. Service innovation: using augmented reality in the IKEA Place app. J. Inf. Technol. Teach. Cases 11 (1), 8–13. https://doi.org/10.1177/2043886920947110.

Parekh, P., Patel, S., Patel, N., Shah, M., 2020. Systematic review and meta-analysis of augmented reality in medicine, retail, and games. Visual Computing for industry, Biomed. Art 3 (1), 21. https://doi.org/10.1186/s42492-020-00057-7.

Pham, T., Vermeulen, J., Tang, A., & MacDonald Vermeulen, L. (2018). Scale impacts elicited gestures for manipulating holograms. *Proceedings of the 2018 Designing Interactive Systems Conference*, 227–240. https://doi.org/10.1145/3196709.3196719.

Plank, T., Jetter, H.-C., Rädle, R., Klokmose, C.N., Luger, T., & Reiterer, H. (2017). Is two enough? *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 4548–4560. https://doi.org/10.1145/3025453.3025537.

Poretski, L., Arazy, O., Lanir, J., Nov, O., 2021. Who owns what? Psychological ownership in shared augmented reality. Int. J. Hum. Comput. Stud. 150, 102611. https://doi.org/10.1016/j.ijhcs.2021.102611.

Poushneh, A., Vasquez-Parraga, A.Z., 2017. Discernible impact of augmented reality on retail customer's experience, satisfaction and willingness to buy. J. Retail. Consum. Serv. 34, 229–234. https://doi.org/10.1016/j.jretconser.2016.10.005.

Qualtrics, 2020. *Qualtrics XM* (October 2022). Qualtrics. https://www.qualtrics.com.

Robinett, W. & Holloway, R. (1992). Implementation of flying, scaling and grabbing in virtual worlds. *In Proceedings of the 1992 symposium on Interactive 3D graphics (I3D*

'92). Association for Computing Machinery, New York, NY, USA, 189–192. https://doi.org/10.1145/147156.147201.

Romano, B., Sands, S., Pallant, J.I., 2021. Augmented reality and the customer journey: an exploratory study. Australas. Mark. J. 29 (4), 354–363. https://doi.org/10.1016/j.ausmj.2020.06.010.

Scholz, J., Smith, A.N., 2016. Augmented reality: designing immersive experiences that maximize consumer engagement. Bus. Horiz. 59 (2), 149–161. https://doi.org/10.1016/j.bushor.2015.10.003.

Scholz, J., Duffy, K., 2018. We ARe at home: how augmented reality reshapes mobile marketing and consumer-brand relationships. J. Retail. Consum. Serv. 44, 11–23. https://doi.org/10.1016/j.jretconser.2018.05.004.

Schrepp, M., Hinderks, A., & Thomaschewski, J. (2014). *Applying the user experience questionnaire (UEQ) in different evaluation scenarios* (pp. 383–392). https://doi.org/10.1007/978-3-319-07668-3_37.

Song, P., Goh, W., Hutama, W., Fu, C., & Liu, X. (2012). A handle bar metaphor for virtual object manipulation with mid-air interaction. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12). Association for Computing Machinery, New York, NY, USA,* 1297–1306. https://doi.org/10.1145/2207676.2208585.

Spittle, B., Frutos-Pascual, M., Creed, C., Williams, I., 2023. A review of interaction techniques for Immersive environments. IEEe Trans. Vis. Comput. Graph. 29 (9), 3900–3921. https://doi.org/10.1109/TVCG.2022.3174805.

Tarre, K., Williams, A.S., Borges, L., Rishe, N.D., Barreto, A.B., & Ortega, F.R. (2018). Towards first person gamer modeling and the problem with game classification in user studies. *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology*, 1–2. https://doi.org/10.1145/3281505.3281590.

Tatzgern, M., Grasset, R., Veas, E., Kalkofen, D., & Seichter, Harmut Schmalstieg, D. (2013). Exploring distant objects with augmented reality. In B. Mohler, B. Raffin, H. Saito, & O. Staadt (Eds.), *Joint Virtual Reality Conference of EGVE- EuroVR (2013)* (pp. 1–9). https://doi.org/10.2312/EGVE.JVRC13.049-056.

Tatzgern, M., Orso, V., Kalkofen, D., Jacucci, G., Gamberini, L., Schmalstieg, D., 2016. Adaptive information density for augmented reality displays. 2016 IEEE Virtual Real. (VR) 83–92. https://doi.org/10.1109/VR.2016.7504691.

Taylor, S.A., Baker, T.L., 1994. An assessment of the relationship between service quality and customer satisfaction in the formation of consumers' purchase intentions. J. Retail. 70 (2), 163–178. https://doi.org/10.1016/0022-4359(94)90013-2.

Team, Rs., 2020. *RStudio: Integrated Development For R*. RStudio. PBC. http://www.rstudio.com/.

Viola, E., Solari, F., & Chessa, M. (2022). Small objects manipulation in immersive virtual reality. *Proceedings of the 17th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications*, 233–240. https://doi.org/10.5220/0010905200003124.

Vuletic, T., Duffy, A., Hay, L., McTeague, C., Campbell, G., Grealy, M., 2019. Systematic literature review of hand gestures used in human computer interaction interfaces. Int. J. Hum. Comput. Stud. 129, 74–94. https://doi.org/10.1016/j.ijhcs.2019.03.011.

Wakefield, K.L., Blodgett, J.G., 1994. The importance of servicescapes in leisure service settings. J. Serv. Mark. 8 (3), 66–76. https://doi.org/10.1108/08876049410065624.

Wang, M., Ye, Z.-M., Shi, J.-C., Yang, Y.-L., 2021. Scene-context-aware indoor object selection and movement in VR. 2021 IEEE Virtual Real. 3D User Interfaces (VR) 235–244. https://doi.org/10.1109/VR50410.2021.00045.

Wodehouse, A., Abba, M., 2016. 3D Visualisation for online retail. Int. J. Mark. Res. 58 (3), 451–472. https://doi.org/10.2501/IJMR-2016-027.

Xu, Q., Sundar, S.S., 2014. Lights, camera, music, interaction! interactive persuasion in E-commerce. Communic. Res. 41 (2), 282–308. https://doi.org/10.1177/0093650212439062.

Zhang, J., Balaji, M.S., Luo, J., Jha, S., 2022. Effectiveness of product recommendation framing on online retail platforms. J. Bus. Res. 153, 185–197. https://doi.org/10.1016/j.jbusres.2022.08.006.