Age and Realism of Avatars in Simulated Augmented Reality: Experimental Evaluation of Anticipated User Experience

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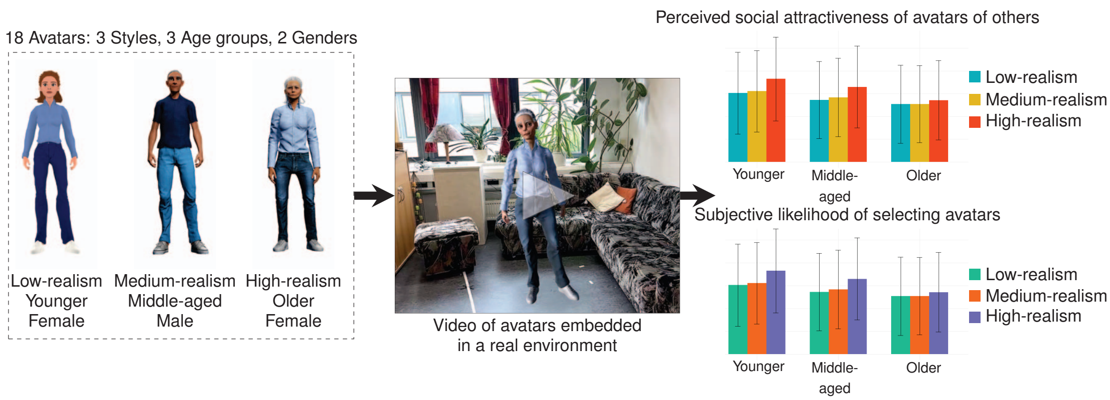

Figure 1: Overview of our study. We investigated the influence of age and rendering style on avatar perception. To do this, we showed $N = 2086$ participants nine videos that simulated an augmented reality (AR) experience and contained an animated virtual human within a real environment from different perspectives. Participants rated the perceived social attractiveness of this 3D model and the likelihood of selecting it as an avatar for themselves.

Abstract

Augmented reality (AR) presents vivid opportunities for interpersonal communication. With the growing diversity of social AR users, understanding their unique needs and perceptions becomes crucial. This study delves into how younger, middle-aged, and older adults perceive avatars with different aging attributes and degrees of realism, focusing on their anticipated user experience within a social AR system. We conducted an online within-subjects experiment involving $N = 2086$ age-diverse participants from Germany who assessed a set of nine gender-matched avatars for their perceived social attractiveness (research question 1 = RQ1) and the likelihood of selecting these avatars for self-representation in social AR (RQ2). The evaluated avatars represented different age groups (younger, middle-aged, and older) and levels of realism (low, medium, and high). We validated both the created avatars and our experimental setup and employed a linear mixed-effects modeling approach to analyze the data. Our findings unveiled a strong preference for younger high-realism avatars as communication partners (RQ1), which was consistent across all participant age groups. Similarly, participants favored younger high-realism avatars for self-representation in social AR (RQ2). However, older adults were more inclined to opt for avatars resembling their actual age. The study highlights the prevalence of age-related stereotypes in avatar-based communication. Similar to face-to-face social interactions, these stereotypes tend to render older avatars less socially attractive than their younger counterparts, irrespective of the avatar's degree of realism. Our results invite considerations on how to combat these stereotypes through a more thoughtful and inclusive avatar design process that encompasses a broader spectrum of aging attributes.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality; Human-centered computing—Human computer interaction (HCI)—HCI design and evaluation methods—User studies

1 Introduction

In the contemporary digital landscape, immersive technologies such as *augmented reality* (AR) offer unique opportunities for interpersonal communication by enabling social interactions with avatars seamlessly integrated into a person's immediate surroundings. An avatar is a perceivable digital representation of a human being, typically controlled by another individual in real-time [1]. Imagine joining a family event as an avatar rather than being unable to attend it due to travel limitations. Or having a relaxed chat with an avatar representing a friend who has relocated to another country. With AR,

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regardless of the hundreds or thousands of kilometers that separate you, communication partners can take a seat beside you on a couch, creating the illusion of their physical presence.

Despite such broad prospects, creating avatars that are able to provide the aforementioned benefits is fraught with challenges, particularly regarding the portrayal of age. Currently, avatars tend to predominantly depict younger individuals, often lacking attributes associated with aging [4, 35]. Furthermore, in most commercially available AR-based social applications such as Magic Leap's Avatar Chat [39] and Microsoft Mesh [31], the avatars typically take on a very cartoon-like form with a low level of facial details, making the integration of age-related characteristics even more problematic.

Another challenge lies in the prevalent inclusion of younger users in experimental studies focused on avatar-based interactions [7]. Meanwhile, the wide application of AR across different domains, from entertainment to healthcare, makes it evident that it successfully caters to individuals of different age groups [25, 62]. Including more age-diverse participants in user studies can help to understand and accommodate their specific needs and foster their satisfaction with mediated communication. This is particularly relevant for older adults who are at risk of loneliness and social isolation and, hence, profit from communication technology to maintain social contacts [22].

With this research gap in mind, the present study aims to investigate the perception of aging attributes in avatars of different degrees of realism among younger, middle-aged, and older adults. In particular, we evaluate their *anticipated* user experience (AUX) to forecast the users' attitudes towards different avatars and highlight potential shortcomings and concerns for the development of AR systems that involve social interactions.

The core contributions of our study are as follows:

- Creation of 18 avatars comprising three different age groups, three levels of realism, and two genders. The avatars were validated by a substantial and age-diverse participant pool and can be used in future studies.
- Providing insights into social AR interactions, particularly regarding the applicability of real-world aging stereotypes to avatar-based communication.
- Highlighting the preference for high-realism avatars and offering practical recommendations for the design of avatars in social AR systems.

2 Related Work

2.1 Social Interactions and Augmented Reality

AR has traditionally centered on users' individual experiences with augmented content. However, its scope can also be expanded to accommodate multi-user scenarios, in which two or more collocated users, typically represented by their avatars, engage in interactive and social experiences such as sharing information, exchanging ideas, and expressing interests [15].

AR-based social interactions can be facilitated by a handheld device such as a smartphone or a tablet, or by a head-mounted display (HMD) that has the benefit of providing a more natural field of view from the user's perspective [16, 17, 36]. Socially interacting with a life-size, three-dimensional representation of another person through an HMD can provide a vivid communication experience that closely mimics face-to-face interactions [44, 51, 66]. It can also convey a nuanced perception of gestures and non-verbal cues, resulting in enhanced emotional involvement and a stronger sense of social presence compared to conventional digital communication forms [3, 8, 33].

User studies often report that participants describe the experience of communicating in AR as pleasant and fun, which increases their overall engagement with the technology and their willingness to adopt it [6, 17, 51]. This sentiment is particularly prevalent among middle-aged and older adults, whose technology acceptance and adoption are often influenced by the perceived usefulness and playfulness of technological artifacts [52]. In turn, younger adults tend to place greater value on the novelty of social AR, often favoring it over traditional means of digital contact, such as video conferencing [44].

2.2 Perception of Avatars

Communication experiences in virtual evnvironments are shaped by the visual, audial, and behavioral attributes of avatars [9]. While an avatar can take any shape and form, studies have shown that individuals tend to respond more positively to avatars that closely resemble real humans and that they perceive as physically attractive [64]. Conforming to conventional beauty standards that are relevant in face-to-face interactions, they prefer to interact with healthy, tall, well-dressed avatars with slender bodies as opposed to avatars that appear disabled, short, overweight, or wear unfashionable clothing [4, 27, 48, 65].

Gender and aging stereotypes also extend to avatar-based interactions [40, 68]. For example, in online games and virtual worlds, users represented by male avatars are frequently perceived as more aggressive, whereas female avatars are seen as more empathetic and willing to help, rendering them more socially approachable [26, 72]. Similarly, engaging with older avatars in virtual worlds can encourage helpful behavior and influence younger adults' perceptions of older people [71]. However, people represented by older avatars may also be seen as frail and dependent [68].

Apart from their general shape and form, the perception of avatars of others varies based on their degree of realism. Studies suggest that more realistic avatars promote intimate communication exchanges in virtual reality (VR) and AR , both when displayed on a computer screen or through an HMD [56, 63]. At the same time, there is evidence that avatars with a lower degree of realism can also be well received, particularly when interacting with strangers or distant acquaintances through an AR telepresence system [69]. Overall, the question of the necessary level of avatar realism remains a subject of debate and is highly context-dependent, although studies suggest that as individuals age, their preferences tend to lean more toward realistic avatars, bothin terms of the perception of avatars of others and self-representation [54].

The selection of one's own avatar can greatly impact communication dynamics in immersive environments [65]. Depending on the hardware and software possibilities, users typically select avatars from predefined options or create avatars from an uploaded photo, with options for minimal manual customization [27]. Although many users attempt to make an avatar look as similar to them as possible, a close resemblance is not always necessary for a positive communication experience [65]. Irrespective of the medium, selecting an avatar that differs from the user's original looks opens up possibilities for self-expression and exploration, helps to constrain or enhance certain appearance characteristics and personality traits, and allows users to create a new idealized version of themselves [4, 50].

2.3 Anticipated User Experience

Users collect experiences with innovative technologies long before they actually use them for the first time [19]. This is often referred to as *anticipated user experience* (AUX) and is defined as the user's expectations, needs, and desires that arise from their anticipated interactions with a product concept, even before the physical product comes into existence [45]. Understanding these expectations and evaluating the system's particular characteristics *before* their actual implementation fosters human-centered design processes and promotes the sustainable allocation of the typically limited economic resources during the initial phases of product design and development [42, 67].

To evaluate AUX, future technology users are usually asked to imagine their use of the future product based on the provided description [42]. For emerging technologies such as AR, however, this can be challenged by the future users' limited knowledge and understanding of the technology itself [23]. Thus, to evaluate the AUX of novel systems, the use of visual design examples (ViDEs) is recommended instead of purely verbal or textual explanations of the future system setup [46]. For example, ViDEs depicting an avatar-based social interaction in AR can help to evaluate the design of these avatars before implementing them in the system prototype [45].

Assessing AUX can also benefit the participants themselves by empowering them and providing them with a sense of agency in shaping the technology's design process [23]. This can be especially valuable for older adults, a user group often marginalized in technology development due to stereotypes that underestimate their interest and competence in adopting new technological solutions [28].

3 Theoretical Background and Research Questions

Rooted in the *Self-Perception Theory* [2], the *Proteus Effect* [64] suggests that an individual's perceptions of themselves and others can be influenced by the visual characteristics and perceived attractiveness of their avatars. However, what constitutes a perceived (un)attractive being can vary based on the context. For conceptual clarity and given our focus on interpersonal communication, we use the term *social attractiveness* of avatars in the present study.

Social attractiveness can be defined as an individual's desire to socialize with another, similar to what people commonly refer to as "liking" [29]. Generally, the more individuals are socially attracted to one another, the more likely they will communicate with each other and the more satisfied they will be with this communication [30]. In the context of avatar-based communication, it is therefore plausible that creating avatars that are perceived as socially attractive can lead to improved communication satisfaction, a desired outcome for social AR systems.

Specifically, perceived social attractiveness can be facilitated by similarities between individuals, according to *Social Identity Theory* [58]. This includes similarities in general demographics, such as age [57,59,61]. Mainly, the perception of aging and assignment of both positive and negative age-related stereotypes varies between three main age groups: younger adults, middle-aged adults, and older adults [18]. These stereotypes can, in turn, guide communication behavior and perceived social attractiveness both within and between different age groups [14]. Given this background, one might expect differences in perceived social attractiveness both of avatars of different ages and among users of different age groups.

Furthermore, the realism of human-like avatars has been a subject of extensive debate for years, often related to the *Uncanny Valley Effect* [34]. The uncanny valley is an unsettling feeling that many individuals get when technological artifacts get too close to resembling humans [20]. While some studies argue that more realistic avatars foster higher affinity and co-presence [5,56], others recommend limiting the avatars' degree of realism in order to increase their likability and perceived attractiveness [12,55]. Given the major practical implications for avatar design, it is worthwhile to investigate whether an avatar's degree of realism also contributes to its perceived social attractiveness.

Against this backdrop, the present study first aims at answering the following research question (RQ):

RQ1: How are avatar age and avatar realism associated with their social attractiveness as perceived by younger adults (18-39 years old), middle-aged adults (40-59 years old), and older adults (60+ years old)?

During AR-based social interactions, all communication participants are represented by avatars. In Western society, youthfulness is often more valued than the appearance of aging, and negative aging stereotypes have become more prevalent in recent decades [38,47]. Consequently, it's plausible that middle-aged and older users might be more inclined to select avatars that appear younger to represent themselves. Therefore, our second research question focuses on the choice of avatar age and avatar realism in relation to the users' own age:

RQ2: How are avatar age and avatar realism associated with the likelihood of being selected for self-representation by younger adults (18-39 years old), middle-aged adults (40-59 years old), and older adults (60+ years old)?

4 Methods

4.1 Study Design

The study employed a quantitative research approach and was conducted as an online within-subjects experiment. Female and male participants categorized into three age groups (younger, middle-aged, and older adults) evaluated a set of avatars classified according to their depicted age (younger, middle-aged, and older avatars) and degree of realism (low-, medium-, and high-realism avatars).

Since there is no unified age categorization system, this study adopts the classification of adulthood periods commonly used in prior research on intra- and intergenerational communication and defines younger adults as 18-39 years old, middle-aged adults as 40-59 years old, and older adults as 60 years or older [11,24,60].

The study is pre-registered. The complete data set, stimulus material, instruments, analysis script, and supplementary tables are publicly available[1].

4.2 Stimulus Material

We developed a set of 18 avatars for the present study, comprising three different age groups, three levels of avatar realism, and two genders. Previous studies show that users tend to feel uncomfortable if they are uncertain about avatar gender [41]. Therefore, we did not create gender-neutral avatars at this stage.

4.2.1 Avatar Development

The initial step in the avatar creation process involved conceptualization. Distinctive characteristics and traits of each age group were taken into account to ensure accurate representation:

- *Younger* avatars emphasized youthful features, such as smooth skin, bright eyes, and vibrant hair colors.
- *Middle-aged* avatars encompassed a balance of maturity and vitality. We emphasized features that signify a mature age group, including subtle facial lines and greying hair.
- *Older* avatars were designed to showcase the effects of aging. We integrated pronounced age-related features such as wrinkles, age spots, and silver hair, to authentically portray aging.

The choice of visual style for each age group aimed at highlighting our study's desired diversity and contrast. We opted for three distinct rendering styles:

- *Low-realism* avatars relied on exaggerated features, amplified colors, and simplified textures to evoke a playful appeal.
- *Medium-realism* avatars embraced a balance between realism and artistic interpretation, showcasing unique characteristics while maintaining a low-detail aesthetic.

[1] `https://osf.io/uf46b`

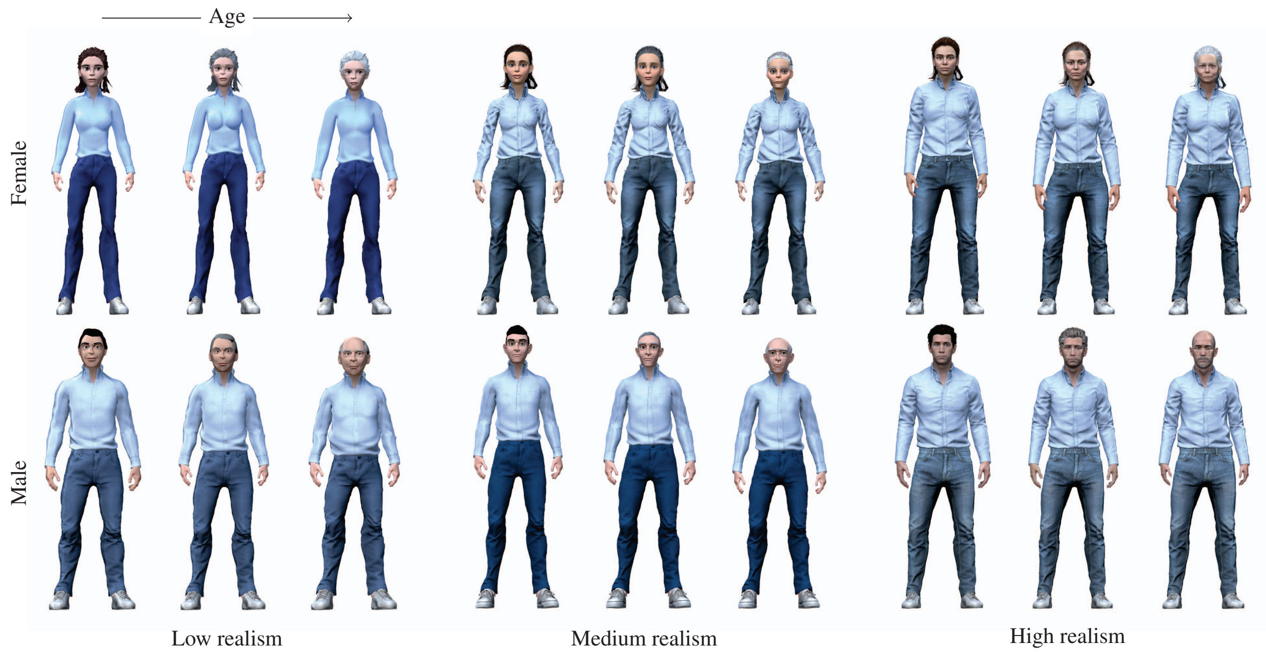

Figure 2: Visualization of all 18 avatars used in the study. Each triplet of avatars shows the age groups (from left to right): younger, middle-aged, and older. All avatars wore the same clothes: blue jeans and a blue shirt.

- *High-realism* avatars aimed to replicate natural human features with a high degree of fidelity, emphasizing lifelike textures and detailed facial expressions.

For each age group, the chosen rendering style influenced the approach to styling and texturing (see Figure 3).

We mainly used *Character Creator 4*[2] for avatar creation and editing, *Adobe Photoshop 2023*[3] for editing textures and materials, and *Blender*[4] for sculpting and refinement of the 3D models.

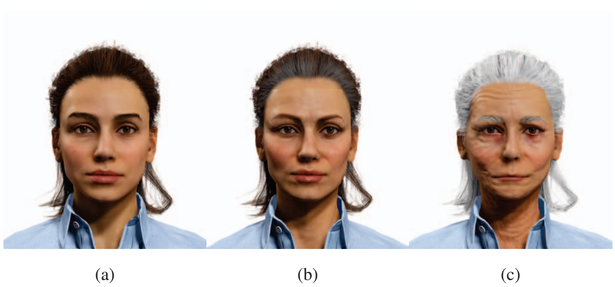

Figure 3: Examples of aging effects shown for the high-realism female avatar: younger (a), middle-aged (b), and older (c).

4.2.2 Avatar Pretest

The initial design of avatars was pretested with an online questionnaire distributed through personal contacts and university mailing lists. $N = 110$ participants evaluated static images of all created avatars. They were asked to indicate the age group of the presented avatar (in 10-year intervals, ranging from under 20 years old to 70 years and above) and how realistic the avatar seemed to them (5-point scale from 1 = very cartoon-like to 5 = very lifelike). The participants in the pre-test successfully perceived the differences between different age groups of avatars and between different degrees of realism (see tables Table S1 and Table S2 in the supplemental material for a detailed overview).

Based on the qualitative feedback provided by some of the participants, avatars underwent minor revisions (e.g., the volume of the male older high-realistic avatar's hair was reduced), leading to the finalized set of 18 avatars used in the main experiment (see Figure 2).

4.2.3 Video Vignette Development

As the present study evaluates AUX, we prerecorded one video of each avatar to emulate the experience of seeing an avatar while wearing a see-through HMD (e.g., Microsoft HoloLens 2).

As a basis for the videos, we recorded a single AR session using an iPad in order to add the actual avatars at a later step. The length of the video was 25 seconds. The video was silent and began with a frontal view of the avatar and then gradually zoomed in on the face while gently swaying from side to side to present the avatar from various angles. After showing a close-up of the avatar's face, the camera moved back to the initial position. We used the same video for each avatar, which means the camera movement was identical in each of them. To add the avatars to the video, we created an application in Unity 2021.3.3f1. This application enabled the execution of the AR session and the smooth integration of virtual objects into the camera's imagery.

Facial blendshapes and pre-recorded animation data were employed to create facial expressions and subtle movements of avatars. For a slightly more realistic visualization, a simple directional light was added and a subtle shadow was introduced below each avatar to improve its integration with the environment. The shadow was realized as a simple circle, with the shadow strength gradually diminishing toward the edges. While more elaborate rendering techniques could easily be added in Unity, we opted for a simple setup

[2] `www.reallusion.com/de/character-creator`, 2023-09-25
[3] `www.adobe.com/de/products/photoshop`, 2023-09-25
[4] `www.blender.org/`, 2023-09-25

that aligns better with the capabilities of HMDs like the Microsoft HoloLens 2.

4.3 Instrument and Measures

The online experiment was conducted using a carefully pretested German-language online questionnaire developed for the present study. In the first part, the characteristics of the study participants were collected. The second part comprised the evaluation of the 18 different avatars. At the end of the questionnaire, participants were asked to indicate their comprehension of the study's objectives, whether they had responded thoughtfully, and offered the possibility to provide open feedback.

4.3.1 Characteristics of Participants

Participants' sociodemographic characteristics such as *age* and *gender* were obtained from the quota variables used during the sampling process (see Chapter 4.4).

We collected information related to the *general technology competence* of participants with the Technology Acceptance subscale of the Technology Commitment Scale [37]. The measure consisted of four statements related to technology use (e.g., "I am very curious about new digital developments") evaluated on a scale from 1 (completely disagree) to 5 (completely agree). Items were averaged to produce a total mean score. Higher scores indicated higher levels of general technology competence. The scale showed strong reliability (Cronbach's α = .93, *GLB* = .94).

Next, participants provided information about their *frequency of playing digital games* on a smartphone or computer (4-point frequency scale from "never" to "often") and *previous experience with social AR* (yes/no).

Since RQ2 is related to the self-embodiment in AR, participants were also asked about their *satisfaction with real-life physical appearance* with the Feelings and Attitudes Towards the Body subscale from the Body Investment Scale [43]. The scale consisted of six randomly displayed items (e.g., "I am satisfied with my appearance") rated on a scale from 1 (completely disagree) to 5 (completely agree). Items were averaged to produce a total mean score. Three items with negative polarity were reverse-coded. The resulting scale ranged from 1 (low body satisfaction) to 5 (high body satisfaction). Scale reliability was strong (Cronbach's α = .89, *GLB* = .93).

4.3.2 Avatar Evaluation

In the next step, participants were presented with visual stimuli (videos of avatars) one-by-one and asked to evaluate each of them regarding perceived social attractiveness and subjective likelihood of selecting for self-representation during an AR-based interpersonal communication.

Perceived social attractiveness of avatars of others was measured with the adapted Social Attraction subscale of the Modified Interpersonal Attraction Scale [30]. The scale consisted of 12 items (e.g., "I would like to have a friendly chat with this person") rated on a Likert scale from 1 (completely disagree) to 7 (completely agree). Items were averaged to produce a total mean score. Six items with negative polarity were reverse-coded. The resulting scale ranged from 1 (low perceived social attractiveness) to 7 (high perceived social attractiveness). Scale reliability was strong (Cronbach's α = .93, *GLB* = .96).

Subjective likelihood of selecting avatars for self-representation was measured with the question "How likely would you select this avatar to represent yourself during communication in augmented reality?" rated on a 7-point scale from 1 (not at all likely) to 7 (very likely; based on [10, 13, 41]).

Avatars were presented to participants in random order and the videos began playing automatically upon loading the page to prevent participants from skipping the content. Each participant evaluated a complete set of nine avatars (three age groups of avatars x three degrees of avatar realism) matching their self-reported gender. Empirical evidence points towards better self-identification of users with gender-matched avatars [49, 53]. Hence, to control for possible gender effects, we matched the participants with avatars of their self-reported gender.

4.3.3 Manipulation Check

To evaluate the success of the experimental manipulation, each participant was asked to guess the age of a presented avatar (7-point scale in 10-year intervals, ranging from under 20 years old to 70 years and above) and how realistic the avatar seemed to them (5-point scale from 1 = very cartoon-like to 5 = very lifelike). The manipulation check was administered only for the last avatar presented to each participant to maintain a reasonable experiment duration.

4.4 Participants and Procedure

The required sample size was calculated with G*Power version 3.1.9.7. Based on an a priori sample size calculation for ANOVA fixed effects, main effects, and interactions with 27 groups (α = .01, 1-β = .80, effect size = .10), the minimum sample size required was *N* = 2074.

Participants were obtained through a professional online access panel provider in Germany. They were selected using an uncrossed quota sampling approach, taking into account two sociodemographic variables: gender (50% men, 50% women) and age (33,3% younger adults aged 18-39, 33,3% middle-aged adults aged 40-59, and 33,3% older adults aged 60 years or older). The online panel provider rewarded participants for their participation with points that could be redeemed for online services and goods.

Questionnaire was administered online using EFS survey from QuestBack Unipark[5]. Eligible participants received an invitation link from a panel provider via email. Data was collected in August 2023.

Since we expected that many participants were not familiar with AR-based interpersonal communication, first, a detailed explanation with visual examples was provided to them to demonstrate how such communication takes place. Visual examples included images depicting a fictional communication scenario between a grandmother and her adult grandchildren using a wearable AR system. We used the storyboard illustrations developed for another study in the CO-HUMANICS (Co-Presence of Humans and Interactive Companions for Seniors) project [32]. A clear and simple explanation of social possibilities of AR before the start of the experiment was crucial both for acquiring meaningful results and for obtaining informed consent for participation in the study. Participants who gave informed consent and agreed to proceed with the study could start the online experiment.

A total of *N* = 2364 participants completed the study. During the data cleaning procedure, we eliminated 278 cases with completion times of less than 5 minutes, cases affected by system errors, and instances where participants admitted to not understanding the objective of the study or not providing thoughtful responses. This resulted in a final sample of *N* = 2086 participants (M_{age} = 50.83, SD_{age} = 15.70, 50% women; see Table 1).

4.5 Data Analysis

All analyses were conducted in *R version 4.3.1*.The *tidyverse* package was used for data cleaning and general data wrangling. The packages *psych*, *SjPlot*, *ggpubr*, and *rstatix* were used for an overview of the data and computing descriptive statistics.

The data was analyzed using a linear mixed-effects model (LMM) approach with the *lme4* package.The participant's age group (a between-subjects factor), avatar age (a within-subjects factor), avatar realism (a within-subjects factor), and their interaction were included as fixed effects. By-participant intercept and intercepts for

[5] `www.unipark.com`, 2023-12-22

Table 1: Socio-demographic characteristics of study participants.

Characteristic		*n*	%
Gender	Male	1041	50
	Female	1045	50
Age group	Younger adults	637	31
	Middle-aged adults	705	34
	Older adults	744	36
Previous experience with social AR	yes	350	17
	no	1736	83
Frequency of playing digital games	never	515	25
	rare	353	17
	sometimes	532	26
	often	686	33
		M	*SD*
Technology competence [a]	Younger adults	3.66	1.01
	Middle-aged adults	3.24	1.09
	Older adults	2.80	0.96
Satisfaction with real-life appearance [b]	Younger adults	3.83	0.86
	Middle-aged adults	3.99	0.83
	Older adults	4.12	0.73

Note. N = 2086. Participants were between 18 and 87 years old (M_{age} = 50.83, SD_{age} = 15.70). Percentage values are rounded. Younger adults: 18-39 years old, middle-aged adults: 40-59 years old, older adults: 60 years or older.
[a] – Scale range: 1 (low technology competence) – 5 (high technology competence).
[b] – Scale range: 1 (low body satisfaction) – 5 (high body satisfaction).

the crossed within-subjects factors "avatar age" and "avatar realism" were incorporated as random effects to address repeated measurements and data structure appropriately. For RQ1, the dependent variable was the perceived social attractiveness of avatars of others. For RQ2, the dependent variable was the subjective likelihood of selecting avatars for self-presentation in social AR. The LMM approach was selected due to its flexibility in handling the repeated measures data and complex data structures

The model assumptions were assessed visually with the package *performance*.The normality of residuals and random effects were examined via quantile-quantile (Q-Q) plots and histograms, linearity was verified using scatterplots, and heteroscedasticity of error variances was evaluated through scale location plots. Additionally, data was screened for possible outliers using Cook's distance as a criterion.

For both RQ1 and RQ2, normality plots of residuals and random effects showed light deviations from normality. However, no major deviations or problematic patterns were observed. Other assumptions were satisfied for both RQs.

The significance of the fixed effects (including the two-way and three-way interactions) was evaluated using the R package *lmerTest*, which provides type III analysis of variance (ANOVA)-style significance tables using Satterthwaite's approximation.This allows for the reporting of interpretable degrees of freedom, F-values, and p-values. Effect sizes (η_p^2) were computed with the package *effectsize*.All post hoc analyses, including pairwise comparisons between fixed effect levels, were conducted when appropriate using z-tests on estimated marginal means using the package *emmeans* with Tukey correction for multiple testing. As the study design was approximately balanced, estimated marginal means were equal to the observed means. Therefore, only observed means are reported. Finally, for a more convenient overview of all pairwise comparisons, a compact letter display was generated using *multcomp* package to specify the significant differences between each level of independent variables.

Given the large sample size of the study, we used a significance level of $p < .01$ to reduce the probability of Type I errors and an effect size of $\eta_p^2 > .01$ to ensure meaningful interpretation of effects.

4.6 Ethical Considerations

Participation was voluntary and anonymous. Informed consent was obtained from all participants. Ethical approval was received from the ethics committee of Technische Universität Ilmenau, Germany, on January 19, 2023.

5 Results

5.1 Manipulation Check

Participants correctly perceived the differences between younger avatars (M = 2.83, SD = 0.87), middle-aged avatars (M = 4.13, SD = 0.95), and older avatars (M = 5.53, SD = 1.13), F(2,2083) = 1290.38, $p < .001$, η_p^2 = .55. All groups were significantly different from each other (see Table S3 in the supplemental material for a detailed overview). It should be noted that although participants perceived older avatars as significantly older than younger and middle-aged avatars, the mean rating indicates that participants' evaluation of the age of older avatars was lower than intended. This could be due to some loss of facial details of avatars that occurred during the creation of video vignettes, as well as the inability of participants to have a close-up look at demonstrated avatars.

The perceived differences between all degrees of realism of all avatars were also statistically significant, F(2,2083) = 400.33, $p < .001$, η_p^2 = .28. Participants correctly perceived the differences between low-realism (M = 1.92, SD = 0.80), medium-realism (M = 2.31, SD = 0.80), and high-realism (M = 3.23, SD = 1.06) avatars. However, despite participants perceiving high-realism avatars as significantly more lifelike than low- and medium-realism avatars, overall, the perceived degree of realism of high-realism avatars was unexpectedly low. Similar to the age of displayed avatars, we assume it to be a result of participants' inability to explore the close-up of avatars, especially considering that most differences were concentrated in the faces and skin details of avatars.

Overall, the manipulation check can be considered successful as participants clearly distinguished between different types of avatars. However, we acknowledge its limitations and reflect on them in the interpretation of the main results of the online experiment.

5.2 Perceived Social Attractiveness of Avatars of Others

Overall, younger high-realism avatars were rated as most socially attractive across all age groups (M = 4.51, SD = 1.19). Older low-realism avatars were rated as least socially attractive (M = 3.74, SD = 1.14). Descriptive results for ratings of each avatar in all three participant age groups are summarized in Table 2.

To answer RQ1 and identify differences in perceived social attractiveness ratings of avatars, fixed effects and interactions between participants' age groups, avatar age group, and degrees of avatar realism were investigated. As shown in Table 3, the three-way interaction was negligibly small. However, there was a significant two-way interaction between avatar age group and avatar degree of realism, F(8,8332) = 48.07, $p < .001$, η_p^2 = .02.

The significant two-way interaction was followed up with an investigation of simple effects of avatar age and avatar degree of realism on the perceived social attractiveness of avatars. Since the participant age group did not demonstrate any significant effects on the perceived social attractiveness, we did not run tests for each age group separately, as the ratings are expected to not differ significantly between participants of different age groups.

The simple main effect of avatar age on perceived social attractiveness of avatars was statistically significant for low-realism avatars, F(2,11238.59) = 112.49, $p < .001$, η_p^2 = .02; medium-realism avatars, F(2,11238.59) = 150.21, $p < .001$, η_p^2 = .03; and high-realism avatars, F(2,11238.59) = 461.65, $p < .001$, η_p^2 = .08. This result

Table 2: Perceived social attractiveness of avatars of different ages and degrees of realism in simulated AR.

Avatar age	Avatar realism	Total (N = 2086)		Younger participants (n = 637)		Middle-aged participants (n = 705)		Older participants (n = 744)	
		M	SD	M	SD	M	SD	M	SD
Younger	Low	4.08_c	1.21	4.19	1.16	4.16	1.25	3.92	1.20
	Medium	4.18_b	1.20	4.32	1.16	4.18	1.21	4.05	1.20
	High	4.51_a	1.19	4.65	1.09	4.49	1.21	4.40	1.24
Middle-aged	Low	3.86_e	1.19	3.91	1.16	3.86	1.21	3.83	1.20
	Medium	3.98_d	1.19	4.10	1.10	3.92	1.22	3.90	1.22
	High	4.19_b	1.18	4.27	1.12	4.14	1.21	4.15	1.22
Older	Low	3.74_f	1.14	3.77	1.11	3.71	1.15	3.73	1.15
	Medium	3.77_f	1.21	3.78	1.18	3.73	1.23	3.81	1.23
	High	3.79_{ef}	1.24	3.83	1.21	3.77	1.25	3.79	1.25

Note. Perceived social attractiveness of avatars was measured on a Likert scale ranging from 1 (low social attractiveness) to 7 (high social attractiveness). Means with different subscripts are significantly different, based on pairwise comparisons with Tukey correction for multiple testing. Statistical significance was accepted at $p < .01$ ($\eta_p^2 > .01$) to reduce the probability of Type I errors and ensure meaningful interpretation of effects. The avatar age group x avatar degree of realism interaction was not affected by participant age groups. Hence, the pairwise comparisons were run only on the Total column.

Table 3: Fixed effects and interactions of perceived social attractiveness of avatars of different ages and degrees of realism in simulated AR.

Effects of independent variables	df_{num}	df_{den}	F	p	η_p^2
Participant age group	2	2083	3.80	.02	< .01
Avatar age group	2	4166	441.80	< **.001**	**.17**
Avatar degree of realism	2	4166	170.91	< **.001**	**.08**
Participant age group x avatar age group	4	4166	10.77	< .001	.01
Participant age group x avatar degree of realism	4	4166	1.61	.17	< .01
Avatar age group x avatar degree of realism	4	8332	48.07	< **.001**	**.02**
Participant age group x avatar age group x avatar degree of realism	4	8332	1.99	.04	< .01

Note. N = 2086. df_{num} – degrees of freedom numerator. df_{den} – degrees of freedom denominator. η_p^2 – partial eta squared. Statistical significance was accepted at $p < .01$ ($\eta_p^2 > .01$) to reduce the probability of Type I errors and ensure meaningful interpretation of effects. Statistically significant results are marked in bold.

shows that manipulation of avatar age affected the perceived social attractiveness of all types of avatars across all participant age groups.

The simple main effect of avatar realism on perceived social attractiveness rating was statistically significant for younger avatars, $F(2,11902.01) = 196.00$, $p < .001$, $\eta_p^2 = .03$; and middle-aged avatars, $F(2,11902.01) = 106.55$, $p < .001$, $\eta_p^2 = .02$; but not for older avatars, $F(2,11902.01) = 3.36$, $p = .03$, $\eta_p^2 < .001$. This result shows that participants perceived older avatars as equally socially attractive, irrespective of their degree of realism.

All post hoc pairwise comparisons and corresponding significant differences can be seen in Table 2.

5.3 Subjective Likelihood of Selecting Avatars for Self-Representation

Overall, younger high-realism avatars were most likely to be selected for self-presentation among all participants (M = 3.65, SD = 1.85). Older low-realism (M = 2.54, SD = 1.72) and older medium-realism (M = 2.54, SD = 1.69) avatars were least likely to be selected. Descriptive results for each avatar are summarized in Table 4.

To answer RQ2 and identify differences in the subjective likelihood of selecting avatars for self-presentation, fixed effects and interactions between participant age groups, avatar age groups, and degrees of avatar realism were investigated. Table 5 shows that there was a statistically significant two-way interaction between participant age group and avatar age group, $F(4,4166) = 24.14$, $p < .001$, η_p^2 =.02. Follow-up analyses showed that avatar age manipulation affected the subjective likelihood of selecting avatars for younger participants, $F(2,4166) = 216.03$, $p < .001$, $\eta_p^2 = .09$; middle-aged participants, $F(2,4166) = 182.11$, $p < .001$, $\eta_p^2 = .08$; and older participants, $F(2,4166) = 43.61$, $p < .001$, $\eta_p^2 = .02$. Observed age groups of participants, however, only affected the subjective likelihood of selecting younger avatars, $F(2,2921.94) = 28.67$, $p < .001$, $\eta_p^2 = .02$.

Post hoc pairwise comparisons for participant age group x avatar age group interaction and corresponding statistically significant differences between all age groups are summarized in Table 6.

Similarly to RQ1, there was also a significant two-way interaction between avatar age and avatar degree of realism, $F(8,8332) = 42.12$, $p < .001$, η_p^2 =.02. Follow-up analyses showed that avatar age manipulation had a statistically significant effect on the subjective likelihood of selecting low-realism avatars, $F(2,11043.78) = 112.92$, $p < .001$, $\eta_p^2 = .02$; medium-realism avatars, $F(2,11043.78) = 151.77$, $p < .001$, $\eta_p^2 = .03$; and high-realism avatars, $F(2,11043.78) = 413.66$, $p < .001$, $\eta_p^2 = .07$. In turn, degree of avatar realism only affected likelihood of selecting younger avatars, $F(2,11905.92) = 235.30$, $p < .001$, η_p^2 =.04; and middle-aged avatars, $F(2,11905.92) = 192.28$, $p < .001$, $\eta_p^2 = .03$; but not older avatars, $F(2,11905.92) = 20.08$, $p < .001$, $\eta_p^2 < .001$.

Post hoc pairwise comparisons and corresponding significant differences can be seen in Table 4

6 Discussion

The present study investigates the perception of aging attributes and different degrees of realism of avatars by younger, middle-aged, and older participants. Based on AUX, we evaluated the perceived social attractiveness of avatars of others (RQ1) and the subjective likelihood of selecting avatars for self-representation (RQ2) in simulated AR environment. To answer the study's RQs, we conducted an online experiment with N = 2086 participants from Germany who assessed a set of gender-matched avatars depicting different

Table 4: Subjective likelihood of selecting avatars of different age groups and degrees of realism for self-representation in simulated AR.

Avatar age	Avatar realism	Total (N = 2086)		Younger participants (n = 637)		Middle-aged participants (n = 705)		Older participants (n = 744)	
		M	SD	M	SD	M	SD	M	SD
Younger	Low	3.02_c	1.80	3.34	1.90	3.01	1.79	2.75	1.66
	Medium	3.10_c	1.78	3.47	1.88	3.08	1.76	2.81	1.65
	High	3.65_a	1.85	4.04	1.84	3.53	1.85	3.42	1.80
Middle-aged	Low	2.72_e	1.70	2.86	1.89	2.60	1.63	2.69	1.58
	Medium	2.83_d	1.72	3.07	1.88	2.69	1.65	2.77	1.62
	High	3.30_b	1.80	3.46	1.86	3.30	1.78	3.14	1.77
Older	Low	2.54_f	1.72	2.72	1.98	2.37	1.58	2.54	1.59
	Medium	2.54_f	1.69	2.65	1.91	2.35	1.57	2.62	1.59
	High	2.71_e	1.74	2.82	1.94	2.59	1.63	2.73	1.67

Note. The subjective likelihood of selecting avatars for self-representation was measured on a Likert scale ranging from 1 (very unlikely) to 7 (very likely). Means with different subscripts are significantly different, based on pairwise comparisons with Tukey correction for multiple testing. Statistical significance was accepted at $p < .01$ ($\eta_p^2 > .01$) to reduce the probability of Type I errors and ensure meaningful interpretation of effects. The avatar age group x avatar degree of realism interaction was not affected by participant age groups. Hence, the pairwise comparisons were run only on the Total column.

Table 5: Fixed effects and interactions of subjective likelihood of selecting avatars of different ages and degrees of realism for self-representation in simulated AR.

Effects of independent variables	df_{num}	df_{den}	F	p	η_p^2
Participant age group	2	2083	11.96	< .001	.01
Avatar age group	2	4166	406.91	< **.001**	**.16**
Avatar degree of realism	2	4166	286.39	< **.001**	**.12**
Participant age group x avatar age group	4	4166	24.14	< **.001**	**.02**
Participant age group x avatar degree of realism	4	4166	0.67	.62	< .01
Avatar age group x avatar degree of realism	4	8332	42.12	< **.001**	**.02**
Participant age group x avatar age group x avatar degree of realism	4	8332	4.25	< .001	< .01

Note. N = 2086. df_{num} – degrees of freedom numerator. df_{den} – degrees of freedom denominator. η_p^2 – partial eta squared. Statistical significance was accepted at $p < .01$ ($\eta_p^2 > .01$) to reduce the probability of Type I errors and ensure meaningful interpretation of effects. Statistically significant results are marked in bold.

age groups (younger, middle-aged, and older avatars) and different levels of realism (low-, medium-, and high-realism avatars).

6.1 Perceived Social Attractiveness of Avatars of Others

Overall, participants found younger high-realism avatars most socially attractive. This finding aligns with previous studies that suggest that perceptions of avatars closely mirror those of real humans and conventional stereotypes relevant in face-to-face interactions can extend to avatars [40]. For instance, it is well-documented that younger individuals tend to be attributed with greater physical attractiveness and, consequently, higher perceived social approachability than older ones [47, 70]. Thus, the overall high perceived social attractiveness of younger avatars was an expected outcome.

However, the lack of difference in social attractiveness ratings between participants of different age groups was unexpected. Based on the assumptions of the *Social Identity Theory* [58] and prior research on intra- and intergenerational communication [14], we initially hypothesized that middle-aged and older adults might demonstrate a preference for middle-aged and older avatars, respectively, as they would potentially relate more to individuals closer to their own age. Surprisingly, despite some subtle variations in evaluations, the overall social attractiveness ranking for all avatar age groups remained consistent among the three participant age groups. This finding shows that the negative age-related stereotypes extend to all age groups.

Besides stereotyping, a plausible explanation for the rejection of older avatars can be the current predominance of avatars depicting younger individuals [4, 35]. While the vast majority of our participants had no previous experience with social AR, most played digital games at least sometimes. Hence, they might have encountered younger digital characters more often than older ones. Although our data doesn't allow for a distinctive conclusion, we assume that seeing middle-aged and older avatars might have been unusual and odd for participants. Nevertheless, given that both middle-aged and older avatars still received positive social attractiveness ratings (mean values of 4.01 and 3.77, respectively, on a scale of 1-7), in our study, we infer their potential for favorable social perception in AR-based communication.

The results regarding RQ1 also align with previous studies emphasizing the preference for more realistic avatars. While we acknowledge the diversity of opinions on this matter within the broader context of the *Uncanny Valley Effect* [34], research on the social aspects of AR consistently suggests a preference for highly realistic avatars in order to foster a sense of connectedness and intimacy during communication [21, 56, 63]. Our study's findings provide a valuable contribution to this body of research, given its explicit focus on perceived *social* attractiveness of avatars, which is a significant predictor for the very desire to engage in communication [30].

It should be noted, however, that different degrees of realism only affected the perceived social attractiveness of younger and middle-aged avatars. Older avatars were consistently perceived as equally (un)attractive, regardless of the level of avatar realism. This suggests that age has a stronger influence on perceived social attractiveness than the avatar's degree of realism. Therefore, improving the degree of realism alone is unlikely to enhance the social perception of older avatars.

Table 6: Subjective likelihood of selecting avatars of different age groups for self-representation in simulated AR.

Avatar age	Younger participants (n = 637)		Middle-aged participants (n = 705)		Older participants (n = 744)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Younger	3.62_a	1.90	3.21_b	1.81	2.99_{bcd}	1.73
Middle-aged	3.13_{bc}	1.89	2.86_{cde}	1.71	2.87_{cd}	1.67
Older	2.73_{def}	1.94	2.43_f	1.60	2.63_{ef}	1.62

Note. N = 2086. Subjective likelihood of selecting avatars for self-representation was measured on a Likert scale ranging from 1 (very unlikely) to 7 (very likely). Means with different subscripts are significantly different, based on pairwise comparisons with Tukey correction for multiple testing. Statistical significance was accepted at $p < .01$ ($\eta_p^2 > .01$) to reduce the probability of Type I errors and ensure meaningful interpretation of effects.

6.2 Subjective Likelihood of Selecting Avatars for Self-Representation

Similar to the results of RQ1, our participants uniformly leaned towards choosing younger high-realism avatars to represent themselves in simulated AR. However, while the preference for high-realism avatars remained consistent across participants of all age groups, distinctions emerged when considering the preferences for avatar aging attributes.

Older adults were less likely to choose older avatars compared to younger and middle-aged ones, but they were also significantly less likely to opt for younger avatars than younger participants. Given that older participants reported a relatively high satisfaction with their real-life physical appearance (M = 4.12, SD = 0.73 on a scale of 1-5; see Table 1), we can suggest that older adults might, in fact, be more inclined to represent themselves with avatars closer to their own age. However, our conclusions regarding this pattern remain limited, as older adults, on the whole, still preferred to be represented by younger avatars.

Surprisingly, middle-aged adults did not exhibit a similar pattern and were significantly less likely to choose middle-aged or older avatars to represent themselves, despite also reporting above-average satisfaction with their physical appearance (M = 3.99, SD = 0.83 on a scale of 1-5; see Table 1). While studies on avatar perception among middle-aged adults are scarce, qualitative insights suggest that middle-aged users, particularly women, often express frustration about having to choose between either younger or older avatars, limiting their ability to represent their actual age authentically [35]. Our findings, however, did not align with the expectation that middle-aged adults would prefer to be represented by avatars of similar age.

In summary, our study indicates a consistent preference for younger avatars over middle-aged and older ones and high-realism avatars over low- and medium-realism ones, both in terms of how participants perceive avatars of others and their choice of avatars for self-representation.

6.3 Limitations and Outlook

The main strengths of the present study are the experimental design and the incorporation of avatars spanning different age groups and levels of realism, as well as a large and age-diverse participant pool. Nonetheless, it is imperative to acknowledge its main limitations.

Firstly, we acknowledge the imperfection of our experimental manipulation. Older avatars were perceived as insufficiently aged, and high-realism avatars did not convincingly convey realism, according to our participants' evaluations. However, since participants were able to correctly distinguish between all experimental conditions, we consider our manipulation sufficient for the goals of the study.

Additionally, our assessment of the perceived social attractiveness of avatars of others predominantly relied on the physical appearance of avatars. Although the avatars exhibited minimal movement and gaze to enhance naturalness, our online experimental setup prevented the incorporation of auditory characteristics and non-verbal cues. While such an approach conforms with the AUX evaluation goals, non-verbal behavior can substantially influence perceived social attractiveness [29]. Thus, we advise following up our findings with experiments that enable user-avatar interaction, as well as to consider potential influence of participants' personality traits on their preferences .

Future studies should also incorporate gender-neutral avatars and mixed-gender dyads. Gender differences were not a focus of this study. However, the gender of both participants and avatars might have influenced avatar perceptions. Incorporating avatars that depict familiar persons or older individuals that might enforce positive aging stereotypes (e.g., movie or book characters) can also present fruitful insights.

Moreover, all avatars employed in the study depicted White individuals. While we did not gather any information on the racial backgrounds of participants during the online experiment, we recognize that the absence of racial diversity among the avatars may have influenced participants' perceptions, particularly in terms of self-representation. The lack of body diversity could also potentially impact participants' identification with the avatars.

Lastly, the perception of avatars while wearing an HMD might differ from their perception on a computer screen. Future studies should build upon the findings of this AUX study by conducting experiments involving a functional prototype of a wearable social AR system.

7 Conclusion

Our study shed light on users' avatar preferences in terms of depicted age and level of realism.

By evaluating participants' AUX in a simulated AR environment, we saw a strong preference for high-realism avatars over low- and medium-realism ones, both in terms of how participants perceive avatars of others and their choice of avatars for self-representation. Aligning with previous research in this field, high-realism avatars can enhance the perception of social presence during AR interactions, closely resembling face-to-face communication [33, 63]. Therefore, we explicitly recommend high-realism avatars for designing social AR systems.

Furthermore, our findings demonstrated a consistent preference for younger avatars over middle-aged and older ones. This highlights the prevalence of age-related stereotypes in avatar-based communication. Similar to face-to-face interactions, aging attributes such as wrinkles, age spots, or gray hair might be associated with reduced social engagement and attractiveness [47, 70].

Based on these findings, we invite considerations for a more inclusive avatar design. Given the increasing diversity of AR users, we advocate for the incorporation of aging attributes that genuinely represent various user age groups. This proactive approach can help mitigate, rather than perpetuate, stereotypes associated with aging, fostering more inclusive and positive social interactions.

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