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Falling in love with AI virtual agents: the role of physical attractiveness and perceived interactivity in parasocial romantic relationships

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With the rapid advancement of media and AI technologies, interactions between virtual agents and humans have become increasingly common. People may establish parasocial relationships (or one-way emotional connections) with virtual agents, which is more appealing to young females and can influence their development and health. To examine the factors influencing the formation of parasocial romantic relationships with AI virtual agents and differentiate these from real romantic relationships, we developed an AI virtual human project and conducted two experiments with an inter-group and mixed design at the behavioral and neural levels. The results revealed that the development of parasocial romantic relationships between female university students and AI agents is affected by the interplay between perceived interactivity and physical attractiveness. Specifically, when physical attractiveness is high, perceived interactivity could significantly predict the degree of parasocial romantic relationship. Furthermore, the study also found that perceived interaction levels affect individuals' experiences with AI virtual agents. High perceived interactivity results in increased activation in the dorsolateral prefrontal cortex, angular gyrus, subcentral area, primary somatosensory cortex, and visual association areas, while suppressing activation of the supramarginal gyrus. This research could deepen our understanding of parasocial romantic relationships and the underlying mechanisms, providing both empirical and theoretical support for future research and practice.

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Introduction

In the contemporary digital age, interactions with various virtual agents (such as Siri, virtual coaches and customer service robots) are becoming increasingly widespread (Tan & Liew, 2020). Virtual agents can fulfill roles in information consultation, remote control, entertainment, and emotional support (Scutella et al., 2024). Especially, with the advancements in artificial intelligence and generative natural language models, virtual agents have become more sophisticated, leading to the emergence of parasocial relationships as a notable social phenomenon (Pal et al., 2023), among which parasocial romantic relationships are especially special, such as Replika and Character AI. In addition to these systems, recent platforms, such as Pi (Inflection AI), Anima AI, and AI-generated streamers like CodeMiko, further expand the range of AI entities embedded in users' everyday lives, offering personalized dialogue, emotional companionship, or even simulated intimacy. These diverse forms of virtual agents reflect the growing complexity of human–AI social interaction. However, recent concerns have also been raised regarding excessive reliance on emotionally responsive AI agents, with some studies linking their overuse to social withdrawal and problematic use patterns (Kooli et al., 2025). These issues highlight the importance of understanding how relationships with companion-like AI develop and what factors shape their emotional impact.

The concept of parasocial relationships was initially introduced to describe media users' reflections on media performers (Horton & Richard Wohl, 1956). With advancements in science and technology, this concept has expanded to encompass one-way connections between users and media figures, who may be either real or fictional (Dibble et al., 2016). Tukachinsky (2010) further differentiated between parasocial friendships and parasocial romantic relationships to distinguish platonic liking from romantic love. Specifically, in the context of parasocial studies, romantic love is characterized by strong obsession, sexual desire, and a drive to interact with virtual agents (Tukachinsky, 2010). Parasocial relationships, especially parasocial romantic relationships, reflect modern society's desire for intimacy and belonging (Pentina et al., 2023), which can improve individuals' mental health, such as enhancing the sense of connection (Bond, 2021; Gleason et al., 2020), reducing stigma (Lee et al., 2021; Parrott et al., 2020), and promoting identity exploration (Ezzat, 2020). It should be acknowledged that parasocial romantic relationships are particularly common among female university students, who are more engaged in these connections with media figures or game characters (Gao et al., 2025; Hua & Xiao, 2023). However, over-reliance on parasocial romantic relationships may lead to maladaptive cognitive and undesirable behavioral consequences, such as unwanted online jealousy, gaming addiction, media overuse and depression and anxiety consequences (Hua & Xiao, 2023; De Bérail et al., 2019; Niu et al., 2022; Yang et al., 2023). In addition, young females who indulge in parasocial romantic relationships may hold idealized romantic beliefs and affect the formation of their true romantic relationships (Tukachinsky & Dorros, 2018). The formation of real-life heterosexual romantic relationships is typically influenced by a complex interplay of factors, including perceived interactivity, physical attractiveness, and other psychological and contextual variables. Repeated and meaningful interactions, especially those involving responsiveness and emotional engagement, can trigger the exposure effect. This process fosters a sense of familiarity that may, in turn, lead to increased liking and a greater likelihood of relationship initiation (Zhou et al., 2023). Physical attractiveness also plays a key role in early-stage romantic attraction. Although research suggests that women may place relatively greater emphasis on traits such as resource availability and long-term investment potential, physical appearance remains an important factor in partner evaluation for both men and women (Ponseti et al., 2022). However, existing literature offers limited insight into the psychological and contextual factors that drive the development of parasocial romantic relationships, as well as how these one-sided attachments differ from—or resemble—real-life romantic bonds.

Based on this context, the present study aims to examine how perceived interactivity and physical attractiveness shape the development of parasocial romantic relationships among female university students in AI-mediated interaction scenarios, and to further compare the neural correlates of parasocial and real-life romantic experiences using functional near-infrared spectroscopy (fNIRS).

Related literatures

Influence of perceived interactivity on parasocial romantic relationships. Interaction and the perception of that interaction are central drivers in the formation of romantic relationships—often outweighing the influence of static personal attributes (Baxter et al., 2022). Research suggests that the development of a relationship depends not only on who the individuals are, but also more critically on what they do during interactions and how they perceive those interactions (Montoya et al., 2018). Under this perspective, the construct of perceived interactivity has received increasing attention in the context of human–media interaction. The perceived interactivity refers to the subjective experience of reciprocal communication when using media technologies. Unlike interactivity, which often denotes the technological features that enable two-way communication, perceived interactivity emphasizes how users psychologically interpret and engage with these features (Kiousis, 2002). As a psychological construct, perceived interactivity directly shapes users' attitudes and behaviors toward digital platforms and virtual agents (Kiousis, 2002; Song & Zinkhan, 2008).

In the romantic content, perceived interactivity may promote feelings of intimacy by simulating mutual responsiveness. According to Sternberg's (1986) triangular theory of love, intimacy is a central component of romantic relationships and arises through experiences of closeness and emotional connection, which can occur even in mediated settings. From a neuropsychological perspective, the Panksepp–Jakobson Hypothesis (PJH) proposes that parasocial and real-life romantic relationships are grounded in similar affective systems, suggesting that emotional bonding with artificial agents may follow mechanisms comparable to those in human relationships (Jacobs et al., 2015; Tukachinsky, 2023). Thus, these suggest that perceived interactivity may play a central role in the development of parasocial romantic relationships by fostering feelings of responsiveness and intimacy. Tukachinsky et al. (2020) suggest that repeated exposure to virtual interactions enables users to develop emotional bonds through indirect engagement in narrated activities. In these contexts, the virtual agents describe their experiences, thoughts, or imagined events through text-based dialog, allowing users to feel involved in the interaction despite the absence of real-time shared activities. Prior research has shown that interactivity enhances parasocial relationships, especially when media figures or agents respond directly to user input (Lee & Watkins, 2016; Wulf et al., 2021). In this study, we define a virtual agent as a digital character with an anthropomorphic appearance that can engage in emotional interaction through text-based communication. With the rise of generative AI technologies, interactions between humans and virtual agents have become increasingly dynamic and personalized. In particular, generative pre-trained transformers (GPT) are capable of producing highly coherent and context-sensitive responses,

simulating reciprocal conversation and emotional responsiveness in ways that resemble real human interaction. These systems can adapt to user input in real time, refer back to prior messages, and express empathy or encouragement, thereby fostering a stronger sense of social presence and perceived interactivity (Binz & Schulz, 2023). Compared to earlier scripted or menu-driven interactions, GPT-based agents offer open-ended, responsive exchanges that may more effectively sustain emotional involvement and support the development of parasocial romantic bonds.

A virtual agent is defined as a virtual character with an anthropomorphic appearance capable of emotional interaction through text via electronic devices in this study. In particular, with the development of artificial intelligence, the interaction between individuals and virtual agents is more and more close to real social interaction.

Therefore, this study hypothesizes that:

H1: Perceived interactivity can positively predict the establishment of a parasocial romantic relationship between female university students and virtual agents

Influence of physical attractiveness on parasocial romantic relationships. Physical attractiveness refers to an individual's esthetic evaluation of appearance (Nguyen et al., 2023), which plays an important role in social interaction, especially in romantic relationships (Li & Zheng, 2019). A-R-D theory holds that individuals with high physical attractiveness can stimulate others' pleasant emotional experience and increase their positive emotions, and promote social interaction and relationships (Burns & Farina, 1987; Li & Zheng, 2019). A considerable number of studies have proved the positive impact of physical attractiveness on romantic relationships in romantic relationships. Generally speaking, external attractiveness can effectively promote the development of intimate relationships. Attractive appearance symbolizes a reliable indicator of reproductive ability and reproductive value (Ponseti et al., 2022). For women, although it is generally secondary to resource-related traits such as status and earning potential, physical attractiveness still functions as a subconscious mechanism for selecting healthy mates, and individuals with highly attractive appearances are more likely to be favored (Little et al., 2011). In addition, the Panksepp-Jakobson hypothesis holds that parasocial relations are an extension of real social relations with the same psychological mechanism (Jacobs & Willems, 2018; Kanazawa, 2002). Therefore, physical attractiveness is also important in the experience of a parasocial romantic relationship (Brown, 2015; Tukachinsky & Stever, 2019). For example, Lieber and Schramm (2017) found that the physical attractiveness of fictional characters can positively predict parasocial romantic relationships, and Yuan et al. (2023) also found that physical attractiveness can positively predict an individual's parasocial relationship with virtual shopping guides. Therefore, the higher the physical attractiveness of the virtual agents, the higher the degree of parasocial romantic relationship between the individuals and the virtual agents.

However, in real relationships, high physical attractiveness does not always mean a good romantic relationship. According to the matching hypothesis, individuals tend to choose partners with similar levels of physical attractiveness, as such pairings are generally more stable. People who are more physically attractive and talkative are perceived by their partners as more likely to be unfaithful, and therefore face higher mate retention behaviors and jealousy, which can affect their romantic relationships (Li & Zheng, 2019). Even in short-term romantic encounters, individuals with high physical attractiveness may elicit psychological distance (feelings of inauthenticity or insecurity in their partners). One study found that in online dating contexts, high attractiveness may also reduce the perceived trustworthiness and create greater interpersonal distance (McGloin & Denes, 2018). Although physical attractiveness and romantic relationship quality often show a complex, nonlinear association in real-world contexts, this complexity may be attenuated in parasocial interactions with virtual agents. Young females engaging with virtual agents tend to idealize these agents and experience greater perceived control and mastery over the interaction, which could reduce the relevance of partner matching effects commonly observed in real relationships (Scott et al., 2024). Consequently, the influence of physical attractiveness on parasocial romantic relationship formation in virtual contexts is more likely to be linear and positive. Moreover, the heightened perceived interactivity of virtual agents may further amplify this effect by enhancing feelings of closeness and engagement, overriding typical concerns such as partner fidelity or jealousy present in offline romantic relationships.

Thus, physical attraction is an important factor for a parasocial romantic relationship. Perceptual interaction is known as the soul of a virtual agent, and the appearance of a virtual agent is considered its bones. The influence of these two factors and how their interaction affects the establishment of parasocial romantic relationships between young females and virtual agents is particularly important in today's era. Therefore, this study aimed to explore the impact of physical attractiveness on parasocial romantic relationships and its interaction with perceived interactivity, and hypothesized that:

H2: The level of physical attractiveness can positively affect the establishment of a parasocial romantic relationship between female university students and virtual agents

H3: The parasocial romantic relationship between female university students and virtual agents is influenced by the interaction between physical attractiveness and perceived interactivity

Neural mechanisms of romantic relationships. When people engage in romantic interactions, it is often accompanied by specific brain activation. Studies have shown that romantic relationships activate certain brain regions(Aron et al., 2005; Xu et al., 2011; Yang, 2017). The photo recall paradigm has been widely used in the activation experiments of romantic love, and relevant studies have found that the medial prefrontal lobe and medial orbitofrontal lobe have statistically significant activation in the early stages of love, and these brain regions are also the active system of dopamine (Aron et al., 2005; Bartels & Zeki, 2004). In addition, other studies have found that the higher the degree of activation of the medial orbitofrontal cortex and the medial prefrontal cortex, the stronger the subjective feeling of passion (Takahashi et al., 2015). In addition, the neural mechanisms of romantic love include deactivation and dextralization in the amygdala, frontal cortex, prefrontal cortex, temporal pole, and temporoparietal junction (Zeki, 2007), which are thought to be associated with emotions (especially negative emotions, such as fear). Some studies suggest that the inactivation of these regions may reflect the immune effect of romantic love on fear (De Carvalho et al., 2010; de la Mora et al., 2010; Shin & Liberzon, 2010).

The Panksepp–Jakobson Hypothesis posits that parasocial relationships are an extension of real-life social bonds, relying on similar psychological mechanisms (Jacobs & Willems, 2018). Prior studies have also shown that the human brain may struggle to distinguish between real and parasocial interactions on a neural level (Kanazawa, 2002). Therefore, based on the existing neural mechanisms of real intimate relationships between

individuals, this study intends to further explore the neural mechanisms of establishing romantic relationships between individuals and virtual agents with different characteristics, and compare them with real romantic partners. Based on the above, this study proposes the following hypotheses exploratively:

H4: The level of perceived interactivity can positively affect the activation level of related brain regions of female university students when they establish a parasocial romantic relationship with virtual agents

H5: The activation level of related brain regions of a real love relationship was significantly higher than that of a parasocial romantic relationship established with a low interaction virtual agent(H5a), but there was no significant difference between a parasocial romantic relationship established with a high interaction virtual agent(H5b)

Study 1: The effects of perceived interactivity and physical attractiveness on parasocial romantic relationships

Methods

Participants. Totally, 117 female students from a university in central China were selected using a convenience sampling method. Participants were required to be either bisexual or heterosexual and to have usage experience with games or generative AI. The participants' ages ranged from 17 to 31 years ($M = 19.79$, $SD = 1.76$). All participants signed an informed consent form and received monetary compensation after completing the experiment. Ethical approval for this study was obtained from the institutional ethics committee affiliated with the first author's university. All procedures adhered to the ethical guidelines for psychological research involving human participants. Samples of the informed consent form and the ethics approval are provided in Appendix 2 and Appendix 3 in the Supplementary Materials.

Experimental design and procedure. A 2 (physical attractiveness: high level vs. low level) × 2 (perceived interactivity: high level vs. low level) between-subjects factorial design was employed. Participants were randomly assigned to one of the four conditions. Ultimately, there were 29 participants in the high attraction/high interaction group, 31 in the high attraction/low interaction group, 27 in the low attraction/high interaction group, and 30 in the low attraction/low interaction group. The dependent variable was scores on the parasocial romantic relationship scale, while prior research has demonstrated that individuals' anxiety about artificial intelligence and their initial knowledge of AI can significantly influence both their adoption behaviors and emotional responses toward AI technologies (Maeda & Quan-Haase, 2024; Wang et al., 2024). Thus, AI anxiety and AI knowledge are included as control variables in the analysis.

Prior to the commencement of the experiment, participants completed a pre-test questionnaire on demographic information, AI knowledge, and AI anxiety. The experimenter then introduced the experimental scenario and tasks. Participants engaged in a conversation with a virtual agent under one of four conditions, randomly assigned: high physical attractiveness with low perceived interactivity, low physical attractiveness with low perceived interactivity, high physical attractiveness with high perceived interactivity, or low physical attractiveness with high perceived interactivity. Upon conclusion of the interaction, participants filled out a post-test questionnaire assessing the virtual entity's physical attractiveness, the interaction content, and the parasocial romantic relationship.

Finally, the experimenter conducted a brief interview to collect participants' feedback and opinions. And the specific schematized sequential steps are shown in Fig. 1.

Experimental material. The description of commonly used male virtual agent images was collected through an early open questionnaire, and 11 corresponding male agent images were generated by *Stable Diffusion* (an AI drawing tool), an AI drawing software. Then, 59 female students from a university in central China participated in the evaluation. The image with the highest score was selected as the experimental material of the high attractiveness group ($M = 4.24$, $SD = 1.70$), and the image with the lowest score was selected as the experimental material of the low attractiveness group ($M = 2.86$, $SD = 1.73$). The effectiveness of the experimental operation was judged by an operability test after the experiment.

To foster an intimate bond between participants and virtual agents, experimental scenarios were selected based on common campus interactions, including mutual assistance, collaborative studying, and expressing love. The virtual agent, portrayed as a supportive and empathetic former friend, provided care during exam stress, celebrated participants' success, and made a romantic confession. In the low-interactivity group, participants imagined the scenarios through written text, while in the high-interactivity group, ChatGPT 3.5, configured via prompt engineering, facilitated situational simulations and plot progression through free dialog, ensuring consistent agent characteristics. Scenario consistency was evaluated using a game content assessment.

Finally, this experiment uses Unity 3D to produce interactive experimental materials, and the specific operation interface is shown in Fig. 2.

Measures. AI knowledge and AI anxiety. This study adapted the robot knowledge scale and the robot anxiety scale (Shi, 2022; Zhou et al., 2018; Nomura et al., 2004), and changed "robot" into "AI". Each scale had 3 items, a total of 6 items, and was measured by a 7-point Likert scale, such as "Compared to most people, I have a greater understanding of AI; I think that if AI develops to the point where it is indistinguishable from a human being, some undesirable things might occur". The Cronbach's α of AI knowledge was 0.91, and the Cronbach's α of AI anxiety was 0.86.

Physical Attractiveness. The "Physical Attractiveness" dimension from the Interpersonal Attraction Scale was selected for measurement (McCroskey & McCain, 1974). It consists of 5 items, such as "I find the appearance of the virtual agent very attractive". And the score is measured using a 7-point Likert scale. The Cronbach's α of physical attractiveness is 0.89.

Perceived interactivity. Referring to previous studies (Li et al., 2024), we adopted the social presence scale to reflect the subjects' feelings about the interactivity of virtual agents. This study used the social presence scale compiled by Khalifa and Shen (2004) and adapted by Gao et al. (2017) to evaluate social presence. The scale contains 5 items, such as "In the game, I have a feeling of contact with the virtual agent". The score is 7 points, with 1 representing "completely disagree" and 7 representing "completely agree". In this study, the Cronbach's α of the scale is 0.74.

Game content. Reference to previous studies (Xu, 2021; Anderson & Ford, 1986) selected the game content consistency scale and asked the participants to rate the images and contents of the games they were exposed to in the experiment, with a total of 6 items, such as "The game is exciting; the game graphics are violent", which were measured by 7-point Likert scale.

Parasocial romantic relationship. The subscale of parasocial romantic relationship of the multiple parasocial relationship scale was used (Tukachinsky, 2010), which had 11 items, such as "For me, the virtual agent is the perfect partner for a romantic relationship", and was measured by a 7-point Likert scale. The Cronbach's α of the parasocial romantic relationship was 0.90.

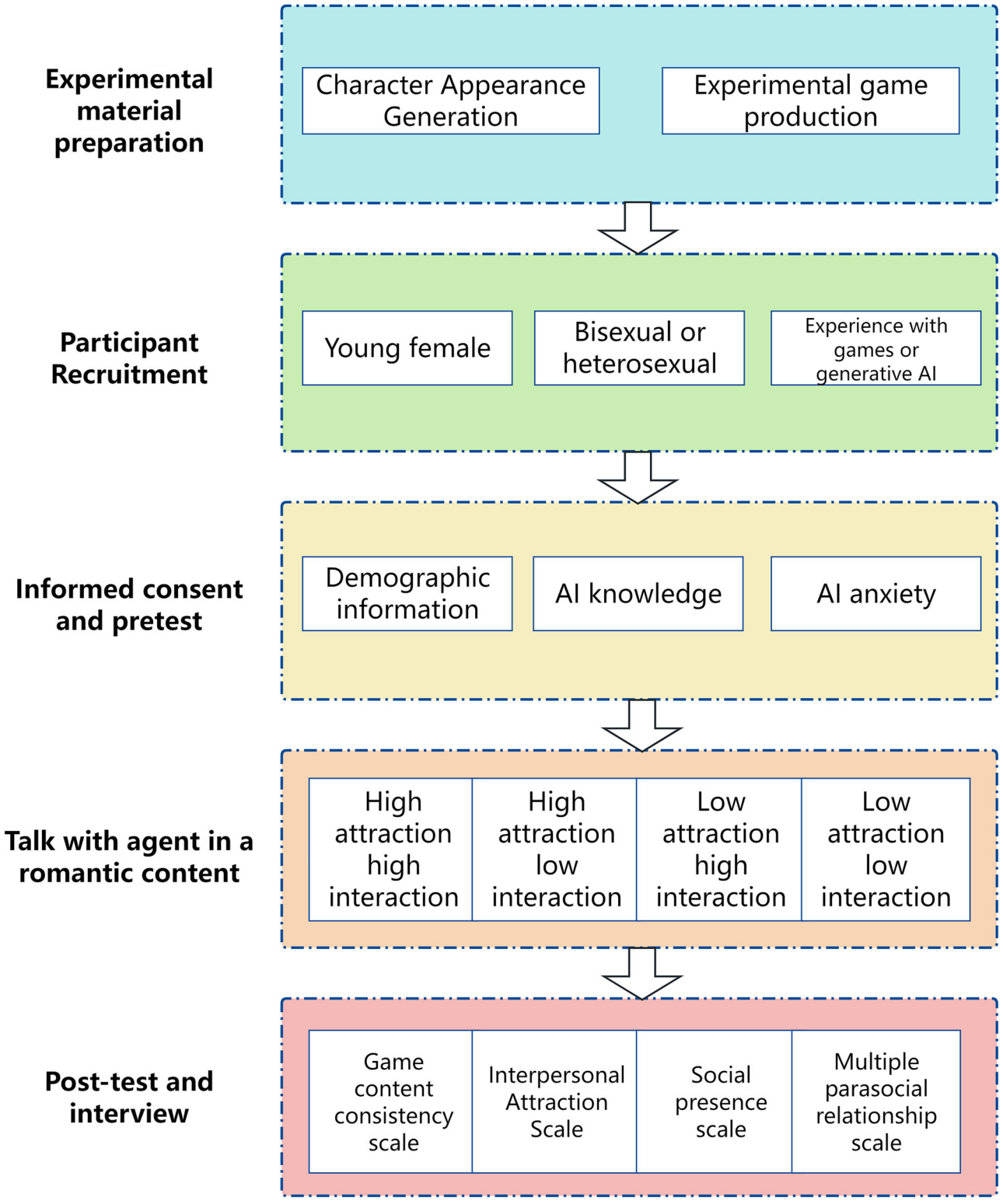

Fig. 1 Schematized sequential steps in study 1.

Results

Consistency checking of game content. To ensure that the experimental manipulation did not unintentionally affect how participants perceived the game content (including game content, game graphics, game difficulty, and emotional experience), we conducted a two-way ANOVA. The results showed that the main effect of perceived interaction and physical attractiveness, and the interaction between perceived interaction and physical attractiveness, were not significant ($p > 0.05$). Therefore, in the four experimental conditions, the participants' feelings about the game content were the same.

Manipulation check of physical attractiveness and perceived interactivity. In order to check the effectiveness of physical

Fig. 2 Four experimental levels of interface (from left to right, top to bottom: high attractiveness low perceived interaction level, low attractiveness low perceived interaction level, high attractiveness high perceived interaction level, low attractiveness high perceived interaction level).

Table 1 Descriptive statistics for each variable under the four experimental conditions.

Perceived interactivity	Physical attractiveness	*N*	AI knowledge		AI anxiety		Parasocial romantic relationship	
			M	SD	*M*	SD	*M*	SD
High		56	3.27	1.17	4.49	1.39	4.46	1.03
	High	29	3.10	1.05	4.64	1.37	4.89	0.86
	Low	27	3.44	1.2	3.33	1.41	4.00	1.00
Low		61	3.51	1.29	4.62	1.45	4.17	1.09
	High	31	3.55	1.34	4.67	1.56	4.21	1.12
	Low	30	3.47	1.26	4.58	1.35	4.13	1.07
Total	High	60	3.33	1.22	4.66	1.46	4.54	1.05
	Low	57	3.46	1.25	4.46	1.37	4.07	1.03

Note: *M* average, *SD* standard deviation. Same below.

attractiveness manipulation of images of different agents, an independent sample T-test was used in this study. The results showed that the attractiveness rating of the agent images in the high-attractiveness group was significantly higher than that in the low-attractiveness group ($t = 9.76$, $p < 0.001$). This suggests that the selection of different agent images can effectively manipulate the physical attractiveness of a virtual agent.

In addition, in order to check the effectiveness of the manipulation of interactivity, an independent sample *t*-test was adopted. The results showed that the participants in the high perceived interactivity group had significantly higher perceived interactivity scores for the virtual agent than those in the low perceived interactivity group ($t = 2.48$, $p = 0.01$). This shows that the manipulation of interactivity in the experiment can significantly affect the participants' perception of the interactivity of the virtual agent.

The effect of physical attractiveness and perceived interactivity on parasocial romantic relationships. To examine the effects of physical attractiveness and perceived interactivity on parasocial romantic relationships, a two-factor analysis of variance was employed, controlling for AI knowledge and AI anxiety. Initially, descriptive statistics were calculated for the variables. The results are presented in Table 1. And their correlations were tested. The results are presented in Table 2. Then, the analysis of variance indicates a significant interaction between perceived interactivity and physical attractiveness on parasocial romantic relationship, with specific results detailed in Table 3.

A significant interaction between physical attractiveness and perceived interactivity was observed, prompting a simple effects analysis. Results indicated that perceived interactivity did not significantly predict parasocial romantic relationships when physical attractiveness was low ($F_{(1,\ 111)} = 0.21$, $p = 0.65$). However, when physical attractiveness was high, perceived interactivity exerted a significant positive effect ($F_{(1,\ 111)} = 6.54$, $p = 0.01$). While the main effect of physical attractiveness reached significance, these findings underscore that the influence of perceived interactivity on parasocial romance is

Table 2 Descriptive statistics and correlations for each variable.

Variable	*M*	SD	1	2	3	4	5
1. Perceived interactivity	0.48	0.50	1				
2. Physical attractiveness	0.51	0.50	0.10	1			
3. Parasocial romantic relationship	4.31	1.06	0.14	0.22*	1		
4. AI knowledge	3.39	1.23	-0.10	-0.05	-0.05	1	
5. AI anxiety	4.56	1.41	-0.05	0.07	0.06	-0.24**	1

Note: $N = 117$. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$. Same below.

Table 3 The effects of perceived interactivity and physical attractiveness on parasocial romantic relationships.

Outcome variables	Predictive variables	SS	MS	*df*	*F*	η_p^2
Parasocial romantic relationship	Perceived interactivity	2.24	2.24	1	2.13	0.02
	Physical attractiveness	6.62	6.62	1	6.28*	0.05
	Perceived interactivity×Physical attractiveness	4.76	4.76	1	4.51*	0.04
	AI knowledge	0.00	0.00	1	0.00	0.00
	AI anxiety	0.20	0.20	1	0.19	0.00

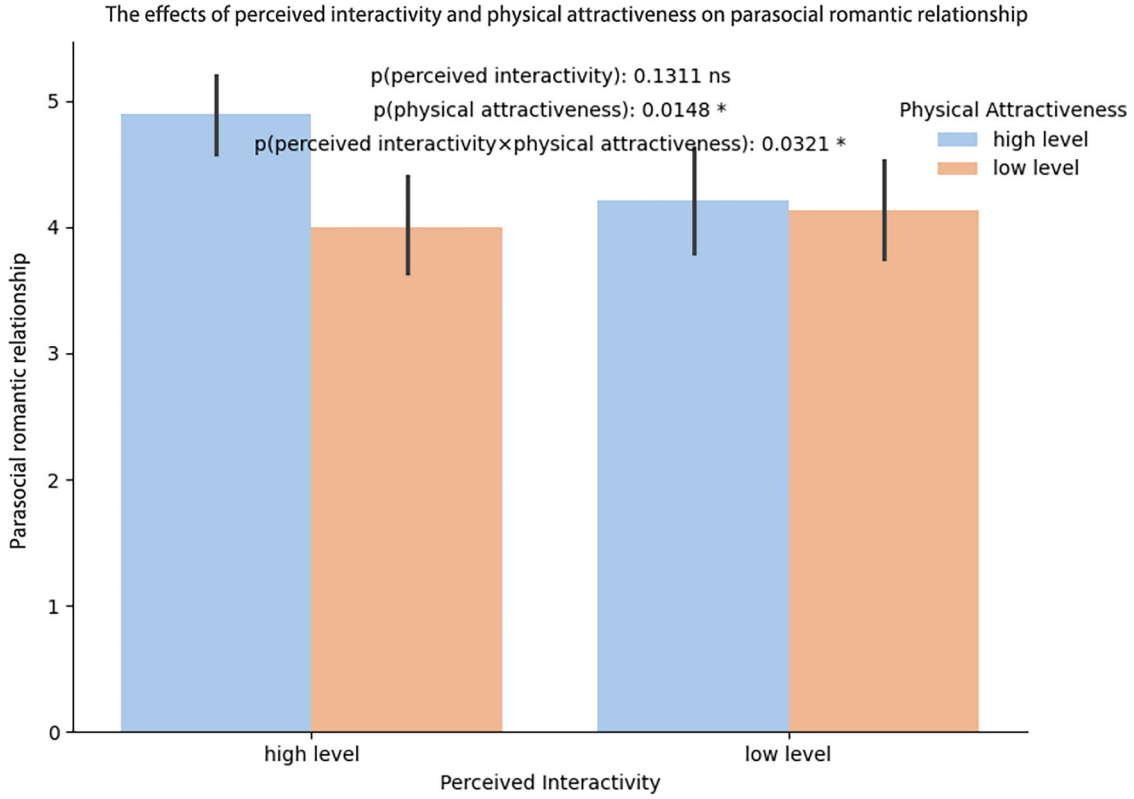

Fig. 3 The effects of perceived interactivity and physical attractiveness on parasocial romantic relationships.

contingent upon physical attractiveness levels. Figure 3 illustrates these effects.

In summary, physical attractiveness significantly influences the establishment of parasocial romantic relationships between individuals and virtual agents. The more physically attractive the virtual agent, the more inclined the individual is to establish a parasocial romantic relationship with the virtual agent. Therefore, H2 is tested. And parasocial romantic relationship is also influenced by the interaction between physical attractiveness and perceived interactivity. Therefore, H3 is tested. In environments where physical attractiveness is high, individuals are more inclined to develop parasocial romantic relationships with virtual agents; moreover, higher levels of perceived interactivity enhance the intensity of parasocial romantic relationships. Nevertheless, further exploration is necessary to deepen our understanding of parasocial romantic relationships with virtual agents. Accordingly, in the second study, we will compare the neural mechanisms of real intimate relationships and parasocial romantic relationships with varying levels of perceived interactivity, aiming to further elucidate the impact of perceived interactivity on parasocial romantic relationships.

Study 2: Parasocial Romantic relationship from the fNIRS perspective

Methods

Participants. According to the sample size recommended by G-power, this study employed a convenience sampling method to select 42 female students from a university in central China. Participants were required to be heterosexual, have prior experience with games or generative AI, and be in a romantic relationship. They ranged in age from 18 to 26 years ($M = 21.48$, $SD = 1.94$). The participants were randomly assigned to either a high-interactivity group or a low-interactivity group, with 21 participants in each group. All participants were right-handed, had normal or corrected-to-normal vision, no history of mental illness, no alcohol allergies, and maintained stable romantic relationships with their partners during the week prior to the study. Before the experiment, the experimenter explained the principles of the instruments to alleviate any concerns. Participants signed informed consent forms and received monetary compensation upon completion of the experiment. During the experiment, participants removed all metal accessories.

Procedure and materials. A single-factor intergroup design was used in this study, where the level of perceived interactivity (high × low) was the between-group variable, and a picture of a real boyfriend was used as a reference. The dependent variables were activation levels of related brain regions. Participants were randomly assigned to the high perceived interactivity group and the low perceived interactivity group, with 21 individuals in each group.

Participants first completed a pre-test questionnaire assessing demographics, romantic history, and current relationship duration. They then engaged in a priming task involving interaction with a virtual agent (as in Study 1) and completed an interim questionnaire measuring game content evaluation and parasocial romantic relationship (as in Study 1). After being equipped with near-infrared and physiological monitoring devices, participants followed computer-based photo recall paradigm instructions (via E-prime 3.0). Finally, they completed a post-test questionnaire assessing passion toward the virtual agent. The specific schematized sequential steps are shown in Fig. 4.

The study used a photo recall paradigm to induce passion, following established neuroimaging protocols (Xu et al., 2011; Yang, 2017). The experimental materials for initiating the task matched those in Study 1 for high physical attractiveness. Photo recall materials included images of virtual characters and real romantic partners. Real partner photos were taken within three months, with neutral expressions, no makeup, accessories, or obstructions, and were edited using Adobe Photoshop. All images were standardized to 512 × 512 pixels with backgrounds removed. Participants first rested for 10 min to establish a baseline, followed by a 120-s blank screen period to stabilize HbO levels. During the experimental phase, participants viewed fixation points (300 ms) followed by 30-s photo presentations, recalling pleasant experiences with their romantic partner or virtual character while avoiding unfamiliar associations (Aron et al., 2005). Between photo trials, a 40-s distraction task involved continuous subtraction of a three-digit number to reset emotional and neurophysiological states. This process cycled four times, lasting 11.33 min, with randomized stimuli presentations to minimize inter-group error. The photo recall paradigm procedure is outlined in Fig. 5.

A total of 31 probes were used in this study, comprising 16 light sources and 15 detectors, spaced 3 cm apart and placed over the prefrontal and bilateral parietotemporal junction areas, forming 42 channels. The sampling rate of the device was 3.91 Hz. The probe arrangement and the brain region channels are detailed in Fig. 6. Spatial co-registration of each channel was performed using the NIRS_SPM package in Matlab, with MNI coordinates and Brodmann area coverage rates presented in Appendix 1.

Analysis methods. In this study, near-infrared data were analyzed using NirsLab v2019.04 software, which is compatible with NIRScout. Initially, the data underwent preprocessing based on criteria such as a variance coefficient (CV%) exceeding 7.5 and a gain percentage (%) greater than 8, to identify and exclude channels with poor signal quality from further analysis. Subsequently, time segments unrelated to the formal experiment were eliminated, and the STD threshold was set to 5 to mitigate interference from swallowing, head movements, breathing, and other factors. Spikes were manually removed. Finally, a band-pass filter ranging from 0.01 to 0.20 Hz was applied to eliminate rapid and slow fluctuations.

Furthermore, acknowledging the delay in hemodynamic coupling responses, a standard hemodynamic response function (HRF) was employed. The Beta values for each channel of each participant were computed using a general linear model to serve as indices for condition comparisons. Analyses were performed utilizing IBM SPSS 26.

Results

Consistency checking of game content. To check the consistency of participants' perceptions of the game content across different experimental conditions, an independent samples *t*-test was conducted. The analysis revealed no significant difference in participants' ratings of the game content between high and low perceived interactivity conditions ($t = 1.31$, $p > 0.05$). Consequently, participants' perceptions of the game content were consistent at both high and low levels of perceived interactivity.

Near-infrared data results. After examination, one participant was excluded due to their rating of the virtual person's attractiveness being more than 3 standard deviations below the mean. Consequently, 41 participants were retained for the subsequent analysis, with 20 participants in the high perceived interactivity condition and 21 in the low perceived interactivity condition.

An independent samples *t*-test was conducted on the 42 brain region channels under conditions of high and low perceived interactivity, employing a bootstrap method with 5000 iterations. The analysis revealed that CH7 demonstrated marginal significance ($t = 1.88$, $p = 0.07$). Therefore, H4 is partially confirmed. Notably, CH7 corresponds to BA9: the dorsolateral prefrontal cortex (refer to Appendix 2 for details).

We performed paired-sample *t*-tests to compare the effects of real boyfriend images versus virtual agent images under low-interaction conditions, employing a bootstrap method with 5000 iterations. The results indicated significant differences in brain regions: BA2(CH19), BA11(CH1, CH8, CH36), BA10(CH3, CH5, CH38, CH39), BA43(CH11), BA21(CH14, CH16, CH18, CH27, CH29), BA39(CH17, CH24), BA37(CH21, CH23), BA19(CH22), BA22(CH25, CH28), and BA46(CH35, CH37). Specifically, activation levels in these regions were higher when participants viewed real boyfriend images compared to the virtual agent images, as detailed in Table 4.

We conducted paired-sample t-tests to compare the real boyfriend images with virtual agent images under high-interaction conditions, employing a bootstrap method with 5000 iterations. The results indicated significant differences in brain regions: BA10(CH5), BA11(CH8), BA21(CH14, CH16, CH27), BA22(CH15), BA37(CH23), and BA40(CH26).

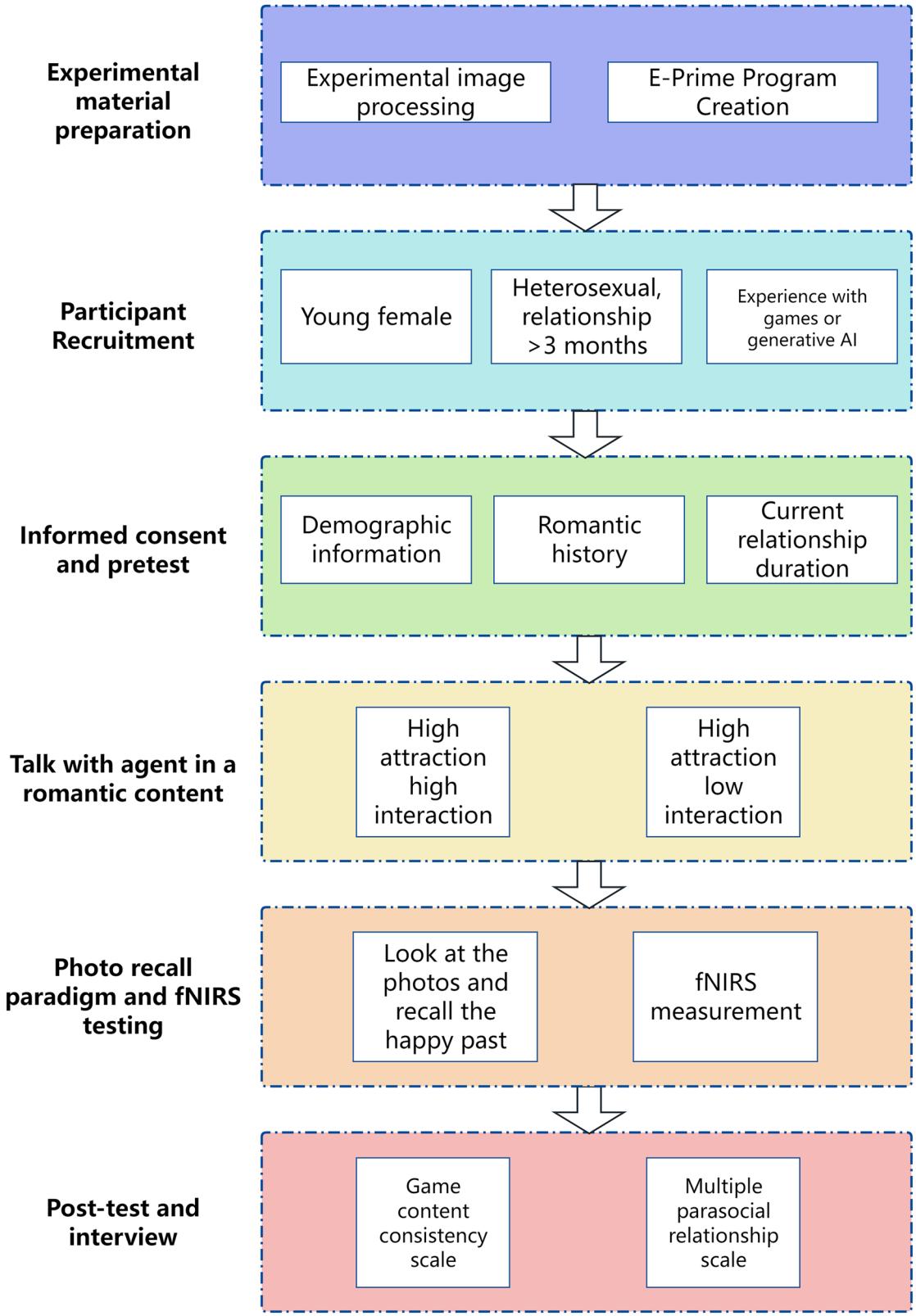

Fig. 4 Schematized sequential steps in study 2.

Specifically, the activation levels in these brain regions were higher when participants viewed real boyfriend images compared to virtual agent images, as detailed in Table 5. Notably, BA2, BA19, BA39, BA43, and BA46, which showed significant differences under low-interaction conditions, did not exhibit significant differences under high-interaction conditions. Conversely, BA40 became significant under high-interaction conditions. Therefore, H5a and H5b are partially confirmed.

General discussion

As technology advances rapidly, a portion of the population, particularly women, has developed relationships with virtual agents that exceed the traditional user-assistant dynamic, forming parasocial romantic relationships. Through a behavioral experiment and a near-infrared experiment, this study explored the influencing factors and neural mechanisms of parasocial romantic relationships between female university students and virtual agents, which has certain implications.

Study 1 found that the interaction between perceived interactivity and the physical attractiveness of virtual agents influences female university students in forming parasocial romantic relationships. Specifically, perceived interactivity significantly enhances parasocial romantic relationships when virtual agents are physically attractive. Study 2 further confirmed the conclusions of study 1 and found that a parasocial romantic relationship has similar neural activation as real romantic relationships. Under high perceived interactivity, individuals demonstrate greater activation of the dorsolateral prefrontal cortex compared to low interactivity situations. Additionally, in such conditions, the differences in brain region activation associated with parasocial romances are less pronounced than in real romantic relationships, indicating a cognitive preference for virtual agents in highly interactive settings. Notably, BA40 exhibits negative activation in these conditions, possibly because individuals struggle to differentiate their emotions from those of virtual agents when interacting with agents driven by large language models, as the agents' responses fully mirror the individuals' inputs.

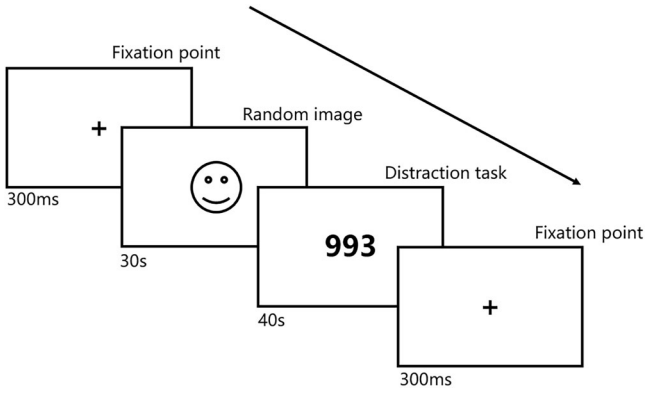

Fig. 5 The experimental procedure.

The role of physical attractiveness and perceived Interactivity. As a heterogeneous experience, romantic love and the formation of other intimate relationships involve different psychological mechanisms, which also apply to parasocial relationships (Tukachinsky, 2010). This study finds that the development of a parasocial romantic relationship is influenced by the interaction between perceived interactivity and physical attractiveness. Perceived interactivity has a significantly positive effect on parasocial romantic relationships only under conditions of high physical attractiveness. Specifically, in the high physical attractiveness group, higher perceived interactivity corresponds to stronger parasocial romantic feelings towards virtual agents. Conversely, in the low physical attractiveness group, regardless of the level of perceived interactivity, individuals' feelings of parasocial romantic relationship with virtual agents are significantly lower than those in the high physical attractiveness group. This may be because highly attractive appearances can trigger physiological arousal

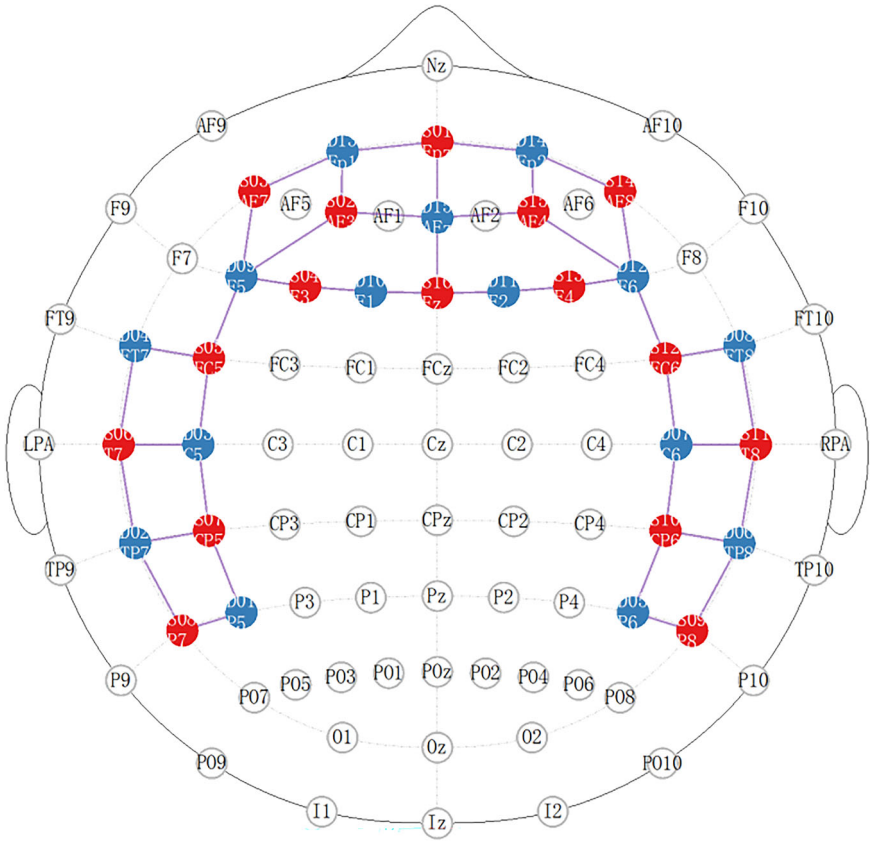

Fig. 6 The probe arrangement.

Table 4 Results of the paired-sample *t*-test for the low interactivity condition.

BA	CH	*df*	*t*
2: Primary Somatosensory Cortex	19	20	2.58*
10: Frontopolar area	3	20	2.80*
	5	20	2.63*
	38	20	2.18*
	39	20	2.67*
11: Orbitofrontal area	1	20	3.24**
	8	20	3.37**
	36	20	3.08**
19: Visual Association Cortex	22	20	2.82*
21: Middle Temporal gyrus	14	20	3.44**
	16	20	2.21*
	18	20	3.77**
	27	20	5.32***
	29	20	2.52*
22: Superior Temporal Gyrus	25	20	2.20*
	28	20	2.88**
37: Fusiform gyrus	21	20	2.77*
	23	20	2.73*
39: Angular gyrus, part of Wernicke's area	17	20	3.37**
	24	20	2.90**
43: Subcentral area	11	20	2.47*
46: Dorsolateral prefrontal cortex	35	20	3.05**
	37	20	2.26*

Note: *BA* Brodmann area, *CH* cannel. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table 5 Results of the paired-sample *t*-test for the high interactivity condition.

BA	CH	*df*	*t*
10: Frontopolar area	5	20	2.32*
11: Orbitofrontal area	8	20	2.32*
21: Middle Temporal gyrus	14	20	2.41*
	16	20	2.49*
	27	20	2.20*
22: Superior Temporal Gyrus	15	20	2.52*
37: Fusiform gyrus	23	20	2.31*
40: Supramarginal gyrus is part of Wernicke's area	26	20	2.28*

Note: *BA* Brodmann area, *CH* cannel. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

based on sexual desire, and physical attractiveness can induce passion, differing from the core components of other intimate relationships (Li et al., 2011). This supports Sternberg's (1986) notion that physical attraction contributes to romantic passion. In real intimate relationships, high physical attractiveness can also bring certain disadvantages. Specifically, high physical attractiveness is frequently perceived as a potential threat to relationship stability, as physical attractiveness often indicates one to be materialistic, indifferent, capricious, conceited, and less cooperative(Ma et al., 2015; Zhang et al., 2017). However, in parasocial relationships, individuals are not concerned with the threat of infidelity, which makes them more inclined to form parasocial romances with highly attractive individuals. For example, the physical attractiveness of online celebrity bloggers can positively predict viewers' evaluation of their recommended products (Liu et al., 2019), and Woods (2024) also finds that satisfying individual aesthetic needs is the main driving force for players to acquire characters and their appearance.

In addition, the intimacy brought by perceived interactivity also influences the emergence of a parasocial romantic relationship. Besides passion, components of romantic love include feelings of intimacy. High perceived interactivity means a more personalized and targeted response that brings a sense of intimacy and connection(Hoffner & Bond, 2022). Furthermore, high perceived interactivity can encourage meaningful self-disclosure between the individual and the virtual agent. Through repeated emotional expression and exposure, individuals can experience a stronger feeling of connection and unity (Hoffner & Bond, 2022), thus fostering intimacy. Additionally, as this study primarily focuses on the establishment of short-term parasocial romantic relationships, physical attractiveness stands out as a crucial visual impression. Without higher physical attractiveness, it may be challenging to quickly form a romantic relationship with a virtual agent. Therefore, under conditions of high physical attractiveness, high perceived interactivity can trigger the highest level of parasocial romantic relationship.

The neural mechanisms of parasocial romantic relationships. Based on the results of Study 1, Study 2 further employed high-attractiveness virtual agent materials to design a single-factor, two-level between-group experiment. This experiment compared virtual agents with varying levels of interactivity to participants' real-life boyfriends. We collected near-infrared data.

The research findings indicate that perceived interactivity influences the establishment of a parasocial romantic relationship. High perceived interactivity conditions increase activation levels in the dorsolateral prefrontal cortex, which is associated with high-level cognitive functions—particularly decision-making, emotion regulation, self-reflection, attention allocation, and social cognition. It plays a crucial role in evaluating others' intentions, understanding complex emotions, and reflecting on personal attitudes (Weissman et al., 2008). Although the results show only marginal significance ($p = 0.07$), they suggest a trend indicating a potential link between BA9 activation and perceived interactivity. BA9, known as the dorsolateral prefrontal cortex, is closely linked to emotion regulation, social interaction, cognitive control, and dopamine release (Sotoyama et al., 2022; Stern et al., 2024). The dialog style of highly interactive virtual agents is more targeted and personalized, potentially eliciting greater social cognitive engagement, thereby prompting deeper thought and emotional investment. While virtual agents are not real emotional interaction partners, their high perceived interactivity may simulate experiences akin to genuine social interactions in participants' brains, thus reflecting a trend in BA9 activation. This was also observed in subsequent analyses. Previous studies have demonstrated that under conditions of high intimacy, there is increased activation in the dorsolateral prefrontal cortex (Azhari et al., 2020). Additionally, research has found that the dorsolateral prefrontal cortex is involved in top-down cognitive control and is associated with regulating positive emotions such as reward and motivation. Other studies suggest that initial romantic attraction is affected by the interplay between physical attractiveness and emotional processing, possibly resulting in high activation levels in the dorsolateral prefrontal cortex during the early stages of romantic attraction (Heatherton & Wagner, 2011; Ueda, 2022). In this study, the marginal significance observed may be due to an insufficient sample size, partially supporting hypothesis H4.

This study also identified several brain regions significantly affected by perceived interactivity, including BA2, BA19, BA39, BA40, BA43, and BA46, through comparisons with real romantic partners. Differences in activation levels of the primary somatosensory cortex and visual association areas were attributed to varying levels of perceived interactivity. Under conditions of high perceived interactivity, virtual agents provide a richer sensory experience, enhancing participants' sensitivity to spatial,

perceptual, emotional, and social cues during interactions, which results in variations in BA2 and BA19 activation levels. Additionally, the angular gyrus, crucial for language comprehension and social cognition, is involved in understanding others' intentions (Rockland & Graves, 2023). Feedback from virtual agents, under high perceived interactivity, is more personalized and unpredictable, leading to differences in angular gyrus activation across interaction levels. The dorsolateral prefrontal cortex remains a focal point of distinction, relating to social cognition and attention allocation (Weissman et al., 2008). Virtual agents with high perceived interactivity levels can elicit more attention and social cognitive engagement, resulting in variations in BA46 activation. This finding suggests that under low perceived interactivity, participants may struggle with processing spatial and perceptual information during interactions with virtual agents, with emotional and intentional communication lacking specificity. However, under high perceived interactivity, participants become more attuned to social-emotional cues from virtual agents, enhancing emotional resonance and self-reflection, allowing for improved emotional regulation and social decision-making. Thus, brain region activations vary across different interactivity levels.

Interestingly, under the high perceived interactivity condition, a significant difference in the activation of the BA40 brain region emerges between conditions involving real partners and virtual agents, which is not evident under low perceived interactivity. Previous research identifies the supramarginal gyrus as crucial for integrating sensory information and distinguishing self from others. Processing social stimuli related to others, rather than those related to oneself, more prominently activates this region (Boehme et al., 2019; Esménio et al., 2019). Furthermore, activation of the supramarginal gyrus is associated with restraining emotional egocentricity bias as part of emotion regulation processes (Silani et al., 2013). In contrast to interactions with real-life partners and virtual agents in low perceived interactivity conditions, where interactions are strictly prescribed, virtual agents under high perceived interactivity utilize ChatGPT-3.5 as the interaction core, relying entirely on participants' text inputs within a defined narrative framework. According to avatar identification theory, individuals experience a merger with the avatar, enhancing cognitive and emotional connections and potentially leading to the temporary suspension of self-awareness. This occurs based on similarity, attractiveness, and fulfillment of psychological needs (Cohen, 2016; Klimmt et al., 2009). To some extent, this dialog resembles "open-ended guidance and questioning" and "mirroring techniques" found in counseling, thereby increasing participants' self-awareness and emotional insight during interactions with virtual agents. Therefore, compared to real partners and virtual agents in low interactivity settings, high-attractiveness virtual agents under high interactivity conditions foster greater identification with the avatar, potentially inhibiting the supramarginal gyrus, a key region for distinguishing self from others.

These findings provide preliminary support for the Panksepp–Jakobson Hypothesis, which posits that parasocial bonds may rely on similar neural mechanisms as real social relationships. Moreover, the observed pattern aligns with evidence that the human brain does not always sharply distinguish between simulated and real social experiences, particularly when agents are perceived as emotionally responsive and interactive. This aligns with previous research suggesting that behaviors and underlying psychological mechanisms from real intimate relationships can be transferred to relationships with virtual agents(Jacobs et al., 2015; Kanazawa, 2002). If virtual agents are able to trigger brain responses associated with real romantic intimacy, this may explain why young females report romantic emotions, albeit unidirectionally, toward these agents. Thus, our neural findings not only complement the self-report data but also offer a potential mechanistic bridge between social cognition, emotional bonding, and parasocial romantic relationships.

Implications

As technology advances rapidly, a portion of the population, particularly women, has developed relationships with virtual agents that exceed the traditional user-assistant dynamic, forming parasocial romantic relationships. Studies suggest that such relationships can enhance a sense of connection, improve coping skills, foster personal development and identity exploration, and reduce bias. However, excessive dependence on parasocial relationships may lead to negative effects, such as depression and anxiety (De Bérail et al., 2019; Hoffner & Bond, 2022; Niu et al., 2022; Yang et al., 2023). Despite this, few studies have investigated why individuals form parasocial romances with virtual agents and how these differ from real romantic relationships. This study broadens the scope of parasocial theory by validating the influencing factors and mechanisms of parasocial romantic relationships and examining the differences in brain region activation between parasocial and real romantic relationships.

In addition, it must be recognized that the feedback provided by virtual agents based on large language models is completely dependent on the user, which may inhibit the user's self-other recognition brain area and may cause what is commonly known as the "big model illusion". It is foreseeable that in some cases, users may overestimate their negative emotional experiences, which may lead to adverse effects. Therefore, based on the results of this study, we believe that developers should establish social consensus-based cognitive and emotional baselines for large language models to mitigate these negative effects.

In the current era of AI, this research also enhances our understanding of a novel form of romantic relationship and provides a theoretical and empirical foundation for the design of human-computer interactions, the formulation of ethical guidelines, and the assessment of mental health impacts.

Limitations and future prospects

However, there are also some points that need further exploration in this study.

Firstly, only short-term parasocial relationships were analyzed, characterized by immediate and surface-level interactions often driven by physical attractiveness. Long-term parasocial relationships, which depend on deeper, enduring connections and central processing routes, were not considered. Future research should adopt longitudinal methods to investigate their formation, stability, and influencing factors.

Second, the sample, predominantly composed of female university students, was small and lacked diversity, potentially limiting the statistical power and external validity of the findings. Future studies should include more diverse gender and age samples to enhance representativeness and generalizability.

Third, the use of flat art styles and AVG game-like interactions may have influenced participants' perceptions of interactivity and attractiveness. Future work should incorporate more realistic virtual agents and diverse scenarios using advanced technologies like VR, AR, and TTS to provide greater immersion and explore the effects of varied media environments.

Fourth, the study used near-infrared (NIR) imaging, which is limited to shallow cortical regions, restricting the analysis to the prefrontal cortex and temporoparietal junction. Core brain areas associated with romantic love, such as the insula, hippocampus, and striatum, remain unexplored. Future studies should utilize imaging modalities like MRI to examine deeper brain regions and provide a more comprehensive neural understanding.

Finally, although the current study does not assess clinical symptoms, future research could examine whether the sustained formation of romantic parasocial bonds with AI agents might have implications for emotional dependence and addiction, particularly among vulnerable populations.

Data availability

In line with the journal's data transparency policy, the data supporting the findings of this study have been made publicly available via the Open Science Framework (OSF) and GitHub. The dataset can be accessed at https://osf.io/kgq67/overview?view_only=4b4339e908424974839df98f0d32bd00 and https://github.com/SiyoKing/Falling-in-love-with-AI-virtual-agents-database. All relevant processed data underlying the reported analyses are included in the repository.

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Author contributions

SJ did the concept construction, wrote the main paper and conducted the experiments and data analysis. FX and ZY were involved in the initial concept construction and assisted with experiments and data analysis. GN and ZZ participated in the concept construction, reviewed the paper, and were supported by funding.

Competing interests

The authors declare no competing interests.

Ethical approval

This study was reviewed and approved by the institutional ethics committee affiliated with the first author's university on March 15, 2024 (approval number: CCNU-IRB-202403090b). All procedures involving human participants were conducted in accordance with the ethical standards of the institutional review board and complied with the principles of the Declaration of Helsinki and its later amendments.

Informed consent

Written informed consent was obtained from all participants after ethics approval in March 2024. Participants were fully informed about the purpose and procedures of the research, their right to withdraw at any time without penalty, and the measures taken to ensure anonymity and confidentiality. Participation was voluntary, and all data were collected and analyzed anonymously.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT4.0 in order to improve language and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Additional information

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