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Smile mimicry smoothens human-virtual human interactions

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ABSTRACT

During social interactions, people often unintentionally mimic each other's behaviors, which can occur at the motor level (e.g. smiles or head movements), and the autonomic level (e.g. pupil size). Mimicry has often been linked with increases in liking and trust and tends to smoothen the bond between interaction partners. However, people with social anxiety are generally less expressive and they may also have altered mimicry behavior. The current study aims to explore the relationship between mimicry, person-perception, and social anxiety levels by having participants interact with virtual humans. Compared to real interaction partners or photographed or filmed actors, virtual humans can be controlled and behaviors very precisely manipulated. Participants observed ten virtual humans telling a neutral story on a computer monitor. At predetermined time points, the virtual humans showed four types of expressions: smiles, head movements, pupil dilation, and blushing. After each story, we measured to what extent participants liked and trusted the virtual humans via the avatar evaluation questionnaire, the desire for future interaction scale, and an investment game. In addition, we assessed participants' social anxiety levels. The results show that participants, regardless of anxiety levels, mimicked the virtual humans' smiles and that smile mimicry is associated with an increased liking and trust toward the virtual humans. These results build on previous research showing that the mimicry of smiles acts as a social glue and also benefits virtual social interactions.

1. Introduction

Mimicry has been shown to occur and smoothen the bond between interacting partners during social interactions (Chartrand and Bargh, 1999; Hess and Fischer, 2022; Kret and Akyüz, 2022). Recent studies demonstrate that mimicry also occurs at the autonomic level and that also at that level, it is associated with prosocial behaviors such as increases in trust (Kret et al., 2015). Interactions between humans and virtual humans are on the rise, but not much is known about mimicry behavior or the possible prosocial benefits during such virtual interactions. In addition, people differ in how expressive they are, and in how sensitive they are to others' expressions. For example, people with high social anxiety levels are generally less expressive (Spokas et al., 2009), show smaller pupillary responses following others' emotional expressions (Keil et al., 2018; Kleberg et al., 2019), and are more prone to blush (Drummond and Su, 2012; Nikolić et al., 2015). Also, research suggests that mimicry may be altered in socially anxious individuals (Abbott et al., 2018; Heerey and Kring, 2007; Vrijsen et al., 2010a, 2010b). In the current study, we investigated the extent to which people mimic virtual humans' behaviors, whether mimicry benefits the interaction, and whether mimicry is influenced by social anxiety levels.

1.1. Mimicry

During social interactions, humans communicate information verbally and nonverbally, in the latter case by sharing their intentions and emotions via facial expressions and body language (Ekman, 1965, 1993; Wallbott, 1998) or via expressions of physiological arousal (Kret, 2015; Prochazkova and Kret, 2017). Oftentimes, emotional expressions are unconsciously mimicked by observers and this occurs at all these different levels, e.g., body posture (Chartrand and Bargh, 1999; Huis in 't Veld et al., 2014a, 2014b; Lafrance and Broadbent, 1976); facial expression (Bavelas et al., 1986; Chartrand and Bargh, 1999; Heerey and Crossley, 2013; Hess and Bourgeois, 2010; Lundqvist and Dimberg, 1995) and arousal (Fawcett et al., 2017; Harrison et al., 2006; Kret et al., 2014). While the mimicry of body posture or facial expressions is

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controlled by the motor muscles, the mimicry of physiological arousal is controlled by the autonomic nervous system (ANS). According to the neurocognitive model of emotional contagion (Prochazcova and Kret, 2017), mimicry starts from the emotion that is expressed by a person during social interaction and is perceived by the interacting partner. These expressions then trigger the interacting partner's own emotional expressions, which results in motor or autonomic mimicry. Since autonomic mimicry is regulated by the ANS, it is much harder to control compared to motor mimicry. Thus, it may provide more information on the perceived intensity or genuineness of the emotion that is mimicked (Kret, 2015).

The mimicry of emotional expressions is usually investigated using photos or videos of actors (e.g., Dimberg et al., 2000; Lundqvist and Dimberg, 1995) or live interactions with humans, either with a human confederate (e.g., Chartrand and Bargh, 1999) or in a dyadic setting with another participant (e.g., Hess and Bourgeois, 2010). Mimicry may be most consistently observed when there is an interaction context, especially when a person seeks affiliation with the interaction partner (Hess and Fischer, 2022). For example, the laughter of a person was mimicked more when the person laughed in response to funny scenes compared to schadenfreude scenes, in which a negative event happened to a third person (Mauersberger et al., 2022). Yet, mimicry studies presenting stimuli on a screen (e.g., Dimberg et al., 2000) have demonstrated that mimicry also occurs without an interaction context. Hence, to some extent, perceiving another person's emotion and responding to it can occur independently from the interaction context (Kret and Akyüz, 2022). Although studying real dyadic interactions is the most ecologically valid one out of these approaches, it is difficult to maintain experimental control. The use of virtual humans can be seen as a 'middle ground', to balance experimental control and ecological validity (Blascovich et al., 2002; Pan et al., 2018). For example, by having a virtual human as the mimickee, we can ensure that the virtual humans only express specific types of behaviors for a specific time duration while at the same time providing an environment that closely replicates a real-life social interaction.

Several studies have investigated whether humans mimic a virtual human's facial or upper body expressions at the motor and autonomic levels (e.g., smiles: Krämer et al., 2013; Mattheij et al., 2015; head movements: Stel et al., 2010; Vrijsen et al., 2010a; pupil size mimicry: Spicer et al., 2021). At the motor level, it was found that participants showed more smiles (Mattheij et al., 2015) and longer smiles (Krämer et al., 2013) when the virtual human smiled. Mattheij et al. (2015) instructed their participants to play a game with a virtual human, where it would say a word with a neutral expression for one second and the participant needed to respond with an associated word within four seconds. During those four seconds, the virtual human would show one out of seven emotional expressions and one of them was a smile. The result indicated that the virtual human's smile was mimicked. However, the participants' expressions may have been influenced by the fact that they were trying to say or think of an associated word. Krämer et al. (2013) provided more control for this possible confound by instructing the participant to only say "yes" or "no" when the virtual human asked the participant questions in an attempt to guess an animal that the participant was thinking of. Their study showed that the participants smiled longer (though not more frequently) when they saw a smiling virtual human compared to a non-smiling virtual human. However, this does not necessarily imply smile mimicry, because the participants' smile data were averaged per condition and the timing of when the smile occurred was disregarded. Thus, more experimental controls could complement previous studies to confirm that smile mimicry occurs in interaction with virtual humans. As for head movement mimicry, Stel et al. (2010) showed that people mimic the virtual human's head movements more than the virtual human's lip, mouth, and eyebrow movements. However, in their study participants were instructed to either mimic or not mimic. Hence, the study provides no information about the spontaneous mimicry of a virtual human's head movements. Vrijsen et al. (2010a) showed that people with higher social anxiety levels mimic the virtual human's head movements less compared with people with lower social anxiety levels, but they did not test whether the sample as a whole mimicked the virtual human's head movements. At the autonomic level, one study investigated pupil dilation mimicry by using a virtual human (Spicer et al., 2021). They showed the virtual humans' faces with either dilated, constricted, or normal pupil size for a few seconds followed by a scrambled image as the interstimulus interval, which is good for experimental control but it made the interaction with the virtual humans less natural. Their result showed that participants' right pupil size increased in response to female virtual human's dilated pupils. The current study builds on these works by studying the mimicry of four different types of expressions made by virtual humans and investigating the relation with participants' social anxiety levels.

1.2. Social consequences of mimicry

Mimicry functions as a "social glue" and makes us feel close to each other (Dijksterhuis, 2005; Lakin et al., 2003). Its relationship with rapport is bi-directional, which means that mimicry creates rapport and rapport creates mimicry (Lakin et al., 2003). For facial expression mimicry specifically, empirical evidence suggests that it promotes liking (Chartrand and Bargh, 1999; Kulesza et al., 2015; McIntosh, 2006; Stel and Vonk, 2010). At the autonomic level, pupil-dilation mimicry promotes trust in in-group partners (Kret et al., 2015) but not in a competitive context (van Breen et al., 2018). One study showed that participants mimic virtual humans' smiles more frequently when the virtual humans were introduced as kind, nice, or self-confident at the beginning of the experiment compared with virtual humans that were introduced as malicious, aggressive, or egoistic (Likowski et al., 2008). There are several studies that investigated the effect of being mimicked by a virtual human (e.g., Aburumman et al., 2022; Bailenson and Yee, 2005; Hale and Hamilton, 2016; Hoegen et al., 2018; Vrijsen et al., 2010b) but, as far as we are aware, not on the effect of the participant mimicking the virtual human. Given the known social benefits of mimicry during human-human interactions, and with the increasing demands for virtual humans in many areas such as coaching (Anderson et al., 2013), healthcare (DeVault et al., 2014), or virtual assistance (Iannizzotto et al., 2018; Matsuyama et al., 2016), it is important to further investigate the role of mimicry in interactions with virtual humans (Wang and Ruiz, 2021).

1.3. Social anxiety may influence mimicry

While mimicry behavior generally has prosocial effects and is frequently observed during social interactions, mimicry seems altered in people with high social anxiety levels (Abbott et al., 2018; Heerey and Kring, 2007; Vrijsen et al., 2010a, 2010b). Social fears vary along a continuum in the general population (Rapee and Spence, 2004). At the upper end, social anxiety disorder is defined as a persistent fear in one or more social situations in which the person is exposed to unfamiliar people or possible scrutiny by others (American Psychiatric Association, 2013). The disorder has a 12-month prevalence of 2–7% in the general population (American Psychiatric Association, 2013). In a recent study among young adults in different countries (Jefferies and Ungar, 2020), up to one-third reported levels of social anxiety that may be indicative of social anxiety disorder, indicating that social fears are particularly common among young adults. Social anxiety influences one's behavior in social situations. For people with high levels of social anxiety, interactions tend to proceed less smoothly, due to high levels of fidgeting, more frequent reassurance-seeking, and poor reciprocity of smiling (Heerey and Kring, 2007). In addition, they often show safety behaviors such as avoiding eye contact, saying little, and not sharing personal information. These behaviors are adopted to avoid making a negative impression but tend to be counterproductive (Alden and Bieling, 1998). Regarding social anxiety in relation to mimicry, Vrijsen et al. (2010a) showed that women with higher social anxiety levels mimic a virtual human's head movements less compared with women with lower social anxiety ($N = 72$). Dijk et al. (2018) found the opposite result which showed that people with high social anxiety levels enhanced their mimicry of smiles ($N = 46$). These findings suggest that mimicry behavior may be moderated by social anxiety. This influence may be explained in two ways. First, the perception of the interacting partner's emotional expression may be altered in people with social anxiety. Second, because both studies investigated motor mimicry, reductions or increases in mimicry may be a strategy to avoid rejection or conflicts, similar to the use of safety behaviors. By including mimicry at the autonomic level, we can understand better what drives the possibly altered mimicry behavior in people with social anxiety. Using virtual humans, the current study is the first in studying four different types of mimicry at the motor and autonomic levels, its putative prosocial effects, and potential modulations by social anxiety.

1.4. Research questions

The current study investigates different types of mimicry during interactions with virtual humans. Considering the previous literature, we formulated three research questions: first, do people mimic virtual human's facial expressions, at the motor (head movement and smile) and autonomic level (pupil dilation and blush)? Second, are mimicry behaviors associated with an increased liking of and trust toward virtual humans? Third, are the putative mimicry behaviors moderated by social anxiety? To our knowledge, no previous research on autonomic mimicry has been done in naturalistic human-virtual human interactions, thus, our research questions concerning autonomic mimicry have an exploratory nature. However, for the research questions concerning motor mimicry, we hypothesize that people mimic the virtual human's expressions (based on Krämer et al., 2013; Mattheij et al., 2015; Stel et al., 2010; Vrijsen et al., 2010a), that mimicry behavior benefits the interaction with virtual humans (Bailenson and Yee, 2005; Hoegen et al., 2018), and that social anxiety is associated with lower mimicry levels especially in head movement mimicry behavior (Vrijsen et al., 2010a).

2. Methods

2.1. Procedure

At the beginning of the experiment, participants were seated in a laboratory room in front of a desk with a 25″ monitor display placed on it. The participants were asked to choose between a Dutch or English version of the experiment. Participants were then provided with information about the study and signed the informed consent form. The participants were told that the study aimed to investigate the relationship between personal characteristics and one's impression of and responses to virtual humans. Next, they filled in a social anxiety questionnaire, read investment game instructions, and answered a few practice questions about the investment game. Afterward, a skin temperature sensor was attached to the right cheek of the participants. Next, the participants put on headphones, the height of the monitor was adjusted so that the participants' gaze was in the center, and a 6-point eye-tracking calibration was performed. Finally, the computer task began. The participants were presented with a virtual human on the monitor display. The virtual human was visible from the chest and above. The participants listened to the story that was told by the virtual humans via the headphones. At the end of each trial, they completed two questionnaires on their liking of the virtual human and played an investment game using the mouse on the desk. The experiment consisted of 10 trials, each with a different virtual human and a different story. At the end of the experiment, the participants were debriefed and then asked to pick a random trial number for the investment bonus. The participants were then given the bonus money and left the laboratory. Each participant session lasted approximately one hour.

2.2. Participants

A sample size computation for a multilevel model was done using GLIMMPSE 3.0.0 (Kreidler et al., 2013), based on the head movement mimicry frequencies for high and low socially anxious participants reported in the study by Vrijsen et al. (2010a) and assuming a medium effect size of the virtual human's expression (target vs other), and an intra class coefficient for the clustering factors Trial and Epoch of 0.65. The significance level was set to alpha = 0.05. For a power of 0.80 to detect a main effect of the virtual human's expression (target vs other) and an interaction effect between the virtual human's expression and social anxiety on the frequency of the target expression in the participant, 48 and 65 participants would be needed respectively.

Sixty-eight participants took part in the study, however, three participants were excluded because of technical issues with the experiment program which resulted in a final sample of 65 (53 female and 12 male). The participants' age ranged from 18 to 39 ($M = 22.4$; $SD = 3.92$). They were students at Leiden University and they were recruited via SONA participant management and recruitment software. As compensation, the participants could choose to receive student participation credits or a monetary reward of €6.5. In addition, they could win a bonus to a maximum of €2.5 in an investment game. The study was approved by the local ethics committee (CEP18–0714/302).

2.3. Stimuli

Stimulus materials consisted of animation displays of 10 virtual humans (5 female and 5 male) telling a neutral story from a virtual indoor room with a bookcase and a desk in the background. The virtual humans were 3D humanoid models created with the Morph Character System version 1.6., implemented in Unity version 2018.2.2f1. Unity was also used to develop the experiment. The virtual humans were programmed to show an expression at 10 time points during each trial. There were four expression types: a smile, a head movement, pupil dilation, or a blush (see Fig. 1). The head movement could be a head

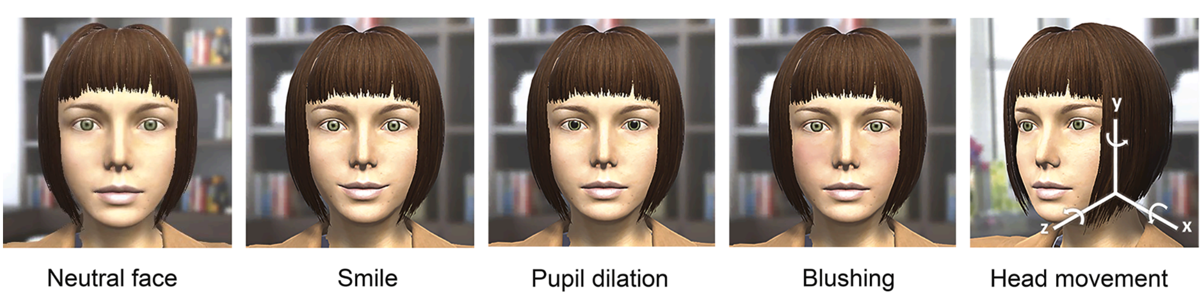

Fig. 1. The Expressions Shown by the Virtual Humans.
Note. The head movement rotation is illustrated by the graph: X-axis is a head nod, Y-axis is a head shake, and Z-axis is a head wobble.

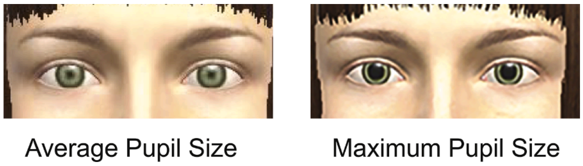

Fig. 2. Virtual Human's Pupil Dilation Expression.

nod, a head shake, or a head wobble (based on Vrijsen et al., 2010a). Each expression was displayed for 4 s with a 9-second neutral expression displayed in between. The first expression was displayed at the 7th second. The events were counterbalanced over the trials. In addition to displaying these events, during each trial the virtual human also showed lip-sync movements which were adjusted to fit with the story, as well as eyebrow raise and eye-squint behaviors that were displayed at relevant times during the story, to give the virtual human a natural appearance.

The 3D models were equipped with a smile and a pupil dilation blendshape (a function that enables changes in the smile and pupil size). Within the 4-second event, the smile increased, or the pupils dilated during the first second from average size to the maximum size. The smile or pupils' size was then stable for 2 s and then decreased back to the normal appearance for the last second (see Fig. 2 for the virtual human's average and maximum pupil size). The blushing event was created by superimposing a red layer on the virtual human's cheeks. This event had a sudden onset, and the reddened face was stable for the whole 4 s. The head movements were created with the Animation function in Unity. The head movement events showed 2 'curves' within 4 s, for example, for the head nod event, the virtual human nodded its head twice during the 4-second time frame.

In each trial, the virtual human showed these expressions while telling a story. Audio recordings of ten different stories (each in Dutch and English), ranging in duration from 2:17 to 2:28 min, had been provided by five female and five male speakers. Stories were randomly assigned to virtual humans for every participant, with the restriction that stories in male voices were assigned to male virtual humans, and stories in female voices were assigned to female virtual humans. The story audio files were processed by the lip-sync automation program RogoDigital LipSync Pro version 1.42 to make the virtual humans show mouth movements automatically according to the syllables. The stories were about daily life events such as playing volleyball, watching movies, or going on a vacation. We conducted a brief study (approved by the local ethics committee, ethics number CEP18–1105/421) to make sure there were no stories that induce strong reactions regardless of the virtual human's behavior.

2.4. Measures

2.4.1. Head movements and smile

The participants' face was recorded via a Logitech HD C270 webcam using the Open Broadcaster Software (OBS) Studio. A master's student (Coder A; CA), who was blind to the hypotheses and the participants' social anxiety levels, coded the video recordings using The Observer XT14 (Noldus Information Technology, The Netherlands). Recordings were coded for 62 out of 65 participants. Two participants could not be included because of camera failure and one participant was excluded because a personal relationship with the coder interfered with objective coding. For exploratory purposes, the following behaviors were coded: smile, frown, other facial movements, head nod, head shake, head wobble, other head movements, and shift position; but only smiles and head movements (aggregating head nod, head shake, and head wobble) were included in the analysis. CA marked the onset and offset time every time a participant showed any of these behaviors, relative to the virtual human onset. Because the virtual human's expression timing was based on the story onset, which was some time after the virtual human appeared on the screen, the time codes of the behaviors were referenced to the story onset time by subtracting the delay (between virtual human onset and story onset).

To define the participant's smile or head movement response, we selected behaviors that started within a certain time window after the avatar's expressions (a response window). The response window duration for smiles and head movements was 8 s. We followed the procedure from (Vrijsen et al., 2010a) which used a 4-second time window after the virtual human's expression offset, but we also added the 4 s4 seconds during which the virtual human's expression was displayed. A python script was created to summarize the coding results into two binary variables "head movement response" (H_{RESP}) and "smile response" (S_{RESP}). A value of 1 referred to a response (participant's head movement or smile) that started to occur within the response window of any of the four virtual human expression types. For example, the first expression in any story occurred from 00:07–00:11, thus, the smile and head movements response window for this event was 00:07–00:15. If a smile onset was coded within this interval, e.g., at 00:15, this would be coded as $S_{RESP} = 1$ on the particular expression, otherwise, $S_{RESP} = 0$. The python scripts resulted in 6090 samples (the coded file of one participant was lost and one participant missed 1 trial because the video recording was started late during the experiment, thus, 61 participants x 10 trials x 10 expressions - 10 expressions).

To assess inter-observer reliability, two other students provided a second coding of the data from the 61 participants that had been coded by CA (CB, $n = 44$; CC, $n = 17$). CB and CC coded the same behavior types as CA and with the same software. The python script was used to retrieve only the head movements and smiles which onset time occurred within the response window. Cohen's kappa (Cohen, 1960) was used to calculate the agreement of H_{RESP} and S_{RESP} between CA–CB and CA–CC. The result showed a moderate agreement between CA–CB on the H_{RESP} ($\kappa = 0.488$, $p < .001$) and S_{RESP} ($\kappa = 0.600$, $p < .001$), and a moderate agreement between CA–CC on the H_{RESP} ($\kappa = 0.578$, $p < .001$) and S_{RESP} ($\kappa = 0.528$, $p < .001$).

During the experiment, there was a technical issue that made the virtual human not show any head movements for 3 participants. These participants' head movement behaviors were still coded and were included in the inter-coder reliability test. However, these 3 participants' data were excluded from the head movement analysis. The final samples that were included in the analysis were 5790 H_{RESP} and 6090 S_{RESP} (see Table 1 for the H_{RESP} and S_{RESP} frequency).

2.4.2. Pupil dilation

Participants' pupil size was measured (in millimeters) using a Tobii X2–60 eye-tracker (sampling rate 60 Hz) and Tobii Pro Software Development Kit (SDK) for Unity. Tobii Pro Eyetracker Manager v1.9.0 was used to calibrate the eye-tracker on 6-points prior to the start of the experiment. To pre-process the pupil size data, we used the PhysioData Toolbox version 0.5 (Sjak-Shie, 2019) and followed the procedure from Kret and Sjak-Shie (2019) which consists of four steps. First, we converted the XML-formated data that was exported by the Tobii Pro SDK to

Table 1
The Frequency of Participant's Smile and Head Movement Response and The Mean and Standard Deviation of Participant's Pupil Size and Skin Temperature Response (RQ1).

	S_{RESP}	H_{RESP}	P_{RESP}	B_{RESP}
Response Found (N_1)	185	114	n/a	n/a
No Response Found (N_0)	5905	5676	n/a	n/a
Mean	n/a	n/a	−0.016	0.002
Standard Deviation	n/a	n/a	0.216	0.041
Total Samples	6090	5790	4487	6080

Note. S_{RESP} and H_{RESP} respectively are smile and head movement responses that occurred within the response window of any virtual human's expression types. P_{RESP} and B_{RESP} respectively are the mean pupil size (in millimeters) and skin temperature (in degrees Celsius) during the response window minus the mean during the baseline of any virtual human's expression types.

a custom MATLAB format that can be read by the PhysioData Toolbox. In this first step, we also defined the baseline and response window for each expression that is shown by the virtual human so that we can retrieve the participant's mean pupil size before the virtual human's pupils started to dilate (baseline) and when the virtual human's pupils dilated (response window). The baseline (0.5 s) started at 0.5 s before the virtual human's expressions onset (−0.5s–0 s) and the response window (2.5 s) started at 1.5 s after the virtual human's expressions onset (1.5s–4 s) (we followed the procedure from Kret et al. (2015)). Second, we filtered the data by identifying and removing the outliers and artifacts. For example, when a participant blinks, their pupil size would appear smaller to the eye-tracker because their eyelids are half open during the blinking process. We would remove a few artifacts during this blinking process since they do not represent the accurate pupil size. Third, the valid pupil sizes were aggregated per 100 ms (based on the standard procedure from Kret and Sjak-Shie (2019)) which was done automatically by the PhysioData Toolbox. Finally, we exported the relevant data for analysis such as the mean pupil size during the baseline and response window, the start and end time of each baseline and response window, and the signal coverage for each baseline and response window.

A participant's pupil size response (P_{RESP}) was summarized from the 63 pre-processed participants' pupil size data using a python script (two out of 65 participants were excluded because of technical difficulties in converting the data). P_{RESP} referred to the baseline-corrected pupil size, which was the pupil size mean during the response window minus the pupil size mean during the baseline. The python script resulted in 6250 samples (5 out of 63 participants each missed 1 trial data because of technical issues, thus, 63 participants x 10 trials x 10 expressions - 50 expressions). Out of the 6250 samples, 863 samples were excluded because the signal coverage either on the baseline or the response window is less than 50%. In addition to that, 9 participants were excluded because out of the possible 100 samples that each participant could have (10 trials x 10 expressions), only less than 50 are still available after the signal coverage exclusion at each sample level (we followed similar exclusion criteria with Kret et al. (2015)). The final P_{RESP} samples that were included in the analysis were 4487 (see Table 1 for the P_{RESP} mean and standard deviation).

2.4.3. Blushing

Blushing was measured by registering the participants' cheek skin temperature (in degrees Celsius) using a Biopac MP150 with SKT 100C module (sampling rate 2000 Hz) and AcqKnowledge 5.0.3. The collected skin temperature data were pre-processed with a similar procedure as the pupil size data using the same software: PhysioData Toolbox version 0.5 (Sjak-Shie, 2019). First, we prepared the raw data by converting the ACQ-formated data and defining the baseline (0.5 s) and response window (12.5 s). We took the longest interval that can be retrieved during the virtual human's neutral face as the response window (i.e. 12.5 s out of 13 s, considering the last 0.5 s as the baseline for the next epoch) because it takes time for the skin temperature to change due to blushing (Drummond and Lim, 2000). The response window started at the virtual human's expression onset (0s–12.5 s) and the baseline started at 0.5 s before the virtual human's expression onset (−0.5s–0 s). Second, we filtered the data by identifying and removing the outliers and artifacts. Third, we processed the valid samples by retrieving the mean skin temperature per 100 ms. Finally, we exported the relevant data for analysis such as the baseline and response window's mean skin temperature, start and end time, and signal coverages.

A participant's blushing response (B_{RESP}) was summarized from the 61 pre-processed participant's skin temperature data using a python script (four out of 65 participants were excluded because of technical issues in retrieving the raw data). B_{RESP} referred to the baseline-corrected skin temperature, which was the skin temperature mean during the response window minus the skin temperature mean during the baseline. The python script results in 6080 samples (2 out of 61 participants each missed 1 trial data because of technical issues, thus, 61 participants x 10 trials x 10 expressions − 20 expressions). Similar exclusion criteria as the pupil size were used, however, it resulted in no data exclusion. Thus, the final B_{RESP} samples that were included in the analysis were 6080 (see Table 1 for the B_{RESP} mean and standard deviation).

2.4.4. Avatar evaluation questionnaire

The avatar evaluation questionnaire (AEQ) with a Cronbach's alpha coefficient of 0.91 (Vrijsen et al., 2010b) was used to measure the liking of virtual humans. The English version was translated to Dutch by a Dutch native speaker. The AEQ was answered on a 7-point Likert scale (1 = not at all; 7 = very much) and it consisted of four questions that measured how much the participant liked the virtual human, how the virtual human came across, and how positively and negatively the participant thought about the virtual human. The Cronbach's alpha for this study's sample indicated a high level of internal consistency $\alpha = 0.915$ (English version $\alpha = 0.912$; Dutch version $\alpha = 0.927$). The participants' answers to the last question were reversed so that higher ratings indicated more liking for all four questions. Then, all answers to the 4 questions were averaged per trial which resulted in 650 AEQ mean scores (65 participants x 10 trials; $M = 5.211$; $SD = 1.154$).

2.4.5. Desire for future interaction scale

The desire for future interaction scale (DFI) (Blöte et al., 2012; adapted from Coyne (1976)) was used as an additional measure of liking. The questionnaire had a good internal consistency of $\alpha = 0.93$. It was answered on a 5-point Likert scale (1 = definitely not; 5 = definitely) and it consisted of seven questions: would be willing to (1) meet the speaker in real life, (2) work on a project with the speaker, (3) sit with the speaker on a three-hour bus ride, (4) invite the speaker to his/her home, (5) get to know the speaker better, (6) seek advice from the speaker, and (7) sit next to the speaker in class. The Cronbach's alpha for this study's sample indicated a high level of internal consistency $\alpha = 0.92$ (English version $\alpha = 0.912$; Dutch version $\alpha = 0.94$). All answers to the 7 questions were averaged per trial which resulted in 650 DFI mean scores ($M = 3.369$; $SD = 0.934$).

2.4.6. Investment game

An investment game that followed a similar procedure from Kret et al. (2015) (adapted from Berg et al. (1995)) was used to measure trust. At the start of the experiment, the participant was instructed as follows. There was a real person represented by the virtual human and each of these persons had decided in the past how much they would like to reciprocate if the participants invested a specific amount of money. For each trial, both the participant and the other person (the virtual human) started with a capital of 6 euros and the participant could choose to invest between €0 to €6. Every investment made would be tripled, so if the participant invested 2 euros, the other person would receive 6 euros. The same would occur with the money returned by the other person, so if the other person decided to return 1 euro, the participant would receive 3 euros. These rules aim to have the participant assume that a partner would return more money if the participant also invested more, thus, the participant needs to trust the virtual human more to invest more money in them. What the other person has indicated to return would not be disclosed to the participant and how much the participant invested would not be reported to the other person. This aims to have the participant's investment decision purely based on their impression of the virtual human. When the experiment ended, the participant could win real money based on one randomly picked investment decision and an associated trustee decision. The trustee's decision was based on a predetermined table of reward money per investment per trial.

The participants were asked how much they would like to invest in the virtual human at the end of every trial. Two participants' investment decisions were excluded from the analyses because they always gave the same investment amount for each trial which indicated that their decisions were not based on their impressions of the different interactions with the virtual humans. Thus, leaving a final sample of 630 scores (63 participants x 10 trials; $M = 2.86$; $SD = 2.576$).

2.4.7. Social anxiety

Social anxiety was measured using Liebowitz Social Anxiety Scale (LSAS) (Liebowitz, 1987). In previous research, the LSAS had an excellent internal consistency ($\alpha = 0.96$; Heimberg et al., 1999). The Cronbach's alpha for this study's sample also indicated a high level of internal consistency $\alpha = 0.937$ (English $\alpha = 0.942$; Dutch $\alpha = 0.885$). The questionnaire has a total of 24 statements, 11 of them are about social interactions (e.g., returning goods to a store) and 13 are about social performance (e.g., giving a report to a group). The participant rated their fear/anxiety (4-point Likert scale; 0 = none; 3 = severe) and avoidance (4-point Likert scale; 0 = never; 3 = usually) regarding each situation. Participants' answers were summarized by adding the total fear and the total avoidance (the maximum possible score was 144). Two participants did not answer 1 to 2 items on the questionnaire; thus, the sum score was calculated with an imputation approach, i.e., the average of the participant's existing answers was multiplied by 48; where 48 is the total number of items.

2.5. Statistical analysis

We conducted a multilevel model analysis for all research questions to account for independence in the data while maintaining the variance in the data. Subjects and their intercepts were always included as a random factor. On each analysis, the unit of analysis was the expression (level 1) nested in trials (level 2) nested in subjects (level 3). All analyses were conducted using IBM SPSS version 27.

To answer whether the participants mimicked the virtual humans' facial expressions at the motor and autonomic level (RQ1), we conducted the analysis separately for the smile, head movement, pupil size, and blushing. In each analysis, we compared the participant's behavioral responses to the virtual human's specific expression versus other expressions. To see whether the participants mimicked the virtual human's smiles, for example, we compared the participant's smile response during the response window of the virtual human's smile epoch versus the virtual human's other expression epochs. For the smile analysis, the fixed effect was the virtual human's smile expression which was treated as a binary variable (1 = smile; 0 = other three expressions pooled into one) and the target was the participant's smile response which was also treated as a binary variable (see Measures section on how the participant's expression response was defined). For the head movements, the fixed effect was the virtual human's head movement expression (binary), and the target was the participant's head movement response (H_{RESP}, binary). The smile and head movement's target distribution and relationship with the linear model was a binary logistic regression because the targets were binary variables. For the pupil size, the fixed effect was the virtual human's pupil dilation expression (binary), and the target was the participant's pupil size response (P_{RESP}, continuous). For the blushing, the fixed effect was the virtual human's blushing expression (binary), and the target was the participant's blushing response (B_{RESP}, continuous). The pupil dilation and blushing's target distribution and relationship with the linear model was a linear regression because the targets were continuous variables. See Table 1 for the summary of the participant's expressions' response frequency (binary responses) or mean and standard deviation (continuous responses).

Table 2
The Frequency of the Participant's Mimicry (RQ2).

	S_{MIM}	H_{MIM}	P_{MIM}	B_{MIM}
Mimicry	62	34	557	754
No Mimicry	1461	1413	596	766
Total Samples	1523	1447	1153	1520

To investigate whether participants' mimicry behavior correlated positively with the avatar evaluation questionnaire, the desire for future interaction, and trust (RQ2), we also conducted the analyses with the emotional expression types separately. In all four analyses, the fixed effect was the participant's mimicry behavior (binary), and the target was the avatar evaluation questionnaire mean score, the desire for future interaction mean score, or trust (continuous). To define a participant's mimicry behavior, we created a new variable "participant's mimicry", this was concluded differently depending on the expression type, but the time window used was the same as the participant's expression response's time window (see Measures section). For the smile and head movement mimicry analyses, the participant's mimicry (S_{MIM}, H_{MIM}) was 1 if the participant showed the behavior (i.e., smile or head movement) within the virtual human's response window for that behavior and 0 otherwise. For the pupil dilation mimicry analysis, the participant's mimicry (P_{MIM}) was 1 if the participant's pupil size median was bigger than the pupil size mean in the virtual human's pupil dilation response window (similar procedure to Prochazkova et al. (2018)). Likewise, the participant's blushing mimicry (B_{MIM}) was 1 if the participant's skin temperature median was bigger than the skin temperature mean in the virtual human's blushing response window. The sample size for all participant's mimicry variables (e.g., S_{MIM}) was lower than the participant's expression response variables (e.g., S_{RESP}) because only the particular virtual human's expression epochs were taken into account (see Table 2 for the frequency of the participant's mimicry behaviors).

Finally, to investigate whether the putative mimicry behavior was moderated by social anxiety (RQ3), we first determined whether the social anxiety levels were varied enough in our sample. The participants' LSAS sum score ($N = 65$) ranged from 4 to 92 ($M = 39.38$; $SD = 19.95$). Shapiro-Wilk test showed that the normality assumption was violated ($W = 0.956$; $p = .022$). The data were skewed to the left which indicated there were more participants with lower social anxiety levels. However, the plot and the standard deviation indicated that the data was varied enough (see supplementary file 3). Therefore, we kept social anxiety in the analysis by treating it as a continuous variable. To answer the research question, we repeated the four analyses of RQ1 but with two added fixed effects on each analysis: social anxiety (continuous) and the interaction between virtual human's expressions and social anxiety.

3. Results

3.1. RQ1: Do people mimic virtual human's facial expressions at the motor and autonomic levels?

The analysis for the first research question showed that the participants were more likely to smile when they saw the virtual human smile compared to when the virtual human showed other expressions [$F(1, 6088) = 7.722$; $p = .005$] (see Table 3 for the estimated means per group). This result indicates that the participants mimicked the virtual human's smile (see Fig. 3).

Participants' head movements were not influenced by the virtual human's head movements [$F(1, 5788) = 1.595$; $p = .207$] (see Table 3 for the estimated means per group). A closer inspection of the participants' head movement data during the response time showed that out of 114 head movements, the participants showed 104 head nods, but only 5 head shakes, and 5 head wobbles. Thus, a follow-up analysis with the same analysis method was conducted to investigate head nod mimicry only. The follow-up analysis did not yield significant results either; the participant's head nod was not influenced by the virtual human's head nod [$F(1,5788) = 1.994$; $p = .158$].

At the autonomic level, there were no significant results. The participant's pupil size was not influenced by the virtual human's pupil dilation [$F(1, 4485) = 0.050$; $p = .823$] and the participant's skin temperature was not influenced by the virtual human's blushing expression [$F(1, 6078) = 0.020$; $p = .888$] which indicated that on average, pupil

Table 3
Estimated Means, Standard Error, and the Confidence Interval's Lower and Upper Limit for All Four Expressions.

Categories	Virtual Human's Expression	Participant's Expression			
		Estimated Mean	Standard Error	95% CI	
				Lower	Upper
Smile	Smile	**.023**	.005	.014	.035
	Others	**.014**	.003	.010	.022
Head Movements	Head movements	.009	.003	.005	.017
	Others	.007	.002	.004	.012
Pupil Dilation	Pupil Dilation	−0.017	.007	−0.031	−0.004
	Others	−0.015	.005	−0.024	−0.006
Blushing	Blushing	.002	.001	<0.001	.004
	Others	.002	.001	.001	.003

Note. The means in bold were significantly different. CI = Confidence Interval.

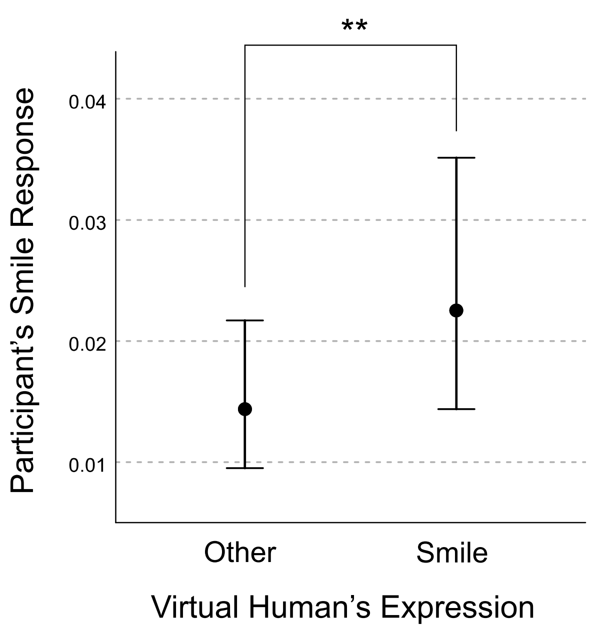

Fig. 3. Estimated Means of Participant's Smile Response Grouped by the Virtual Human's Expression.
Note. Y-axis shows the estimated marginal means of the participant's smile response: an estimated mean of 0 (the lowest value) indicates that the participant never smiled during a response window and an estimated mean of 1 (the highest value) indicates that the participant always smiled during a response window.

dilation mimicry and blushing mimicry did not occur (see Table 3 for the estimated means for all four expressions).

3.2. RQ2: Are mimicry behaviors associated with an increased liking and trust toward virtual humans?

The analysis for the second research question showed a significant effect of smile mimicry on the Avatar Evaluation Questionnaire (AEQ) [F (1, 1521) = 12.592; $p < .001$]. The participants rated the virtual humans more positively when they mimicked the virtual human's smiles (EM = 5.653; SE = 0.153; 95% CI [5.353, 5.954]) compared to when they did not (EM = 5.152; SE = 0.072; 95% CI [5.012, 5.293]). A significant effect was also found on the Desire for Future Interaction (DFI) [F (1, 1521) = 14.431; $p < .001$]; the participants showed a higher desire for future interaction when they mimicked the virtual human's smiles (EM = 3.743; SE = 0.123; 95% CI [3.502, 3.983]) compared to when they did not (EM = 3.329; SE = 0.065; 95% CI [3.203; 3.456]). Similarly, smile mimicry is also associated with increased trust in the virtual human [F (1, 1471) = 9.801; $p = .002$]. The participants trusted the virtual humans more when they mimicked the virtual human's smiles (EM = 3.442; SE = 0.221; 95% CI [3.008, 3.875]) compared to when they did not (EM = 2.846; SE = 0.124; 95% CI [2.602, 3.089]) (see Fig. 4 for the graphs).

However, there was no significant difference found for the other three expressions. Head movement mimicry was not associated with the AEQ score [F(1, 1520) = 0.587; $p = .444$], the DFI score [F(1, 1520) = 0.160; $p = .689$], nor trust [F(1, 1470) = 0.032; $p = .859$]. Pupil dilation mimicry was not associated with the AEQ score [F(1, 1151) = 0.164; $p = .686$], the DFI score [F(1, 1151) = 0.078; $p = .781$], nor trust [F(1, 1106) = 0.086; $p = .770$]. Blushing mimicry also was not associated with the AEQ score [F(1, 1518) = 0.399; $p = .528$], the DFI score [F(1, 1518) = 3.032; $p = .082$], nor trust [F(1, 1468) = 1.010; $p = .315$].

3.3. RQ3: are the putative mimicry behaviors moderated by social anxiety?

The third research question, where we included social anxiety and its interaction with virtual human's expressions as fixed effects, did not result in any significant effects. This means that in our study, social anxiety did not modulate the relationship between the virtual human's expressions and the participant's response for any of the expression types (see all results in Table 4).

4. Discussion

With the rising technology that allows humans to interact more with virtual humans (e.g., Anderson et al., 2013; DeVault et al., 2014; Iannizzotto et al., 2018; Matsuyama et al., 2016), more behaviors that occur in human-human interaction might be needed to smoothen the interaction between humans and virtual humans. Mimicry is one behavior that has prosocial benefits, and this study shows that it also applies to human-virtual human interaction. Our findings show that smile mimicry occurs in an interaction with a virtual human. We also show that smile mimicry benefits the interaction in terms of liking (i.e., the avatar evaluation and the desire for future interaction) and trust towards the virtual humans. We will discuss this key finding and our other findings in detail below.

4.1. Mimicry at the motor and autonomic levels

For the first research question, our results show that smile mimicry occurs in a human-virtual human interaction. The present study controlled for some possible confounds in previous studies and confirmed previous results which suggested that people mimic virtual humans' smiles (Krämer et al., 2013; Mattheij et al., 2015). In Mattheij et al. (2015), the participants' expressions may be influenced by the fact that they were trying to say or think of a word. In our study, this possible

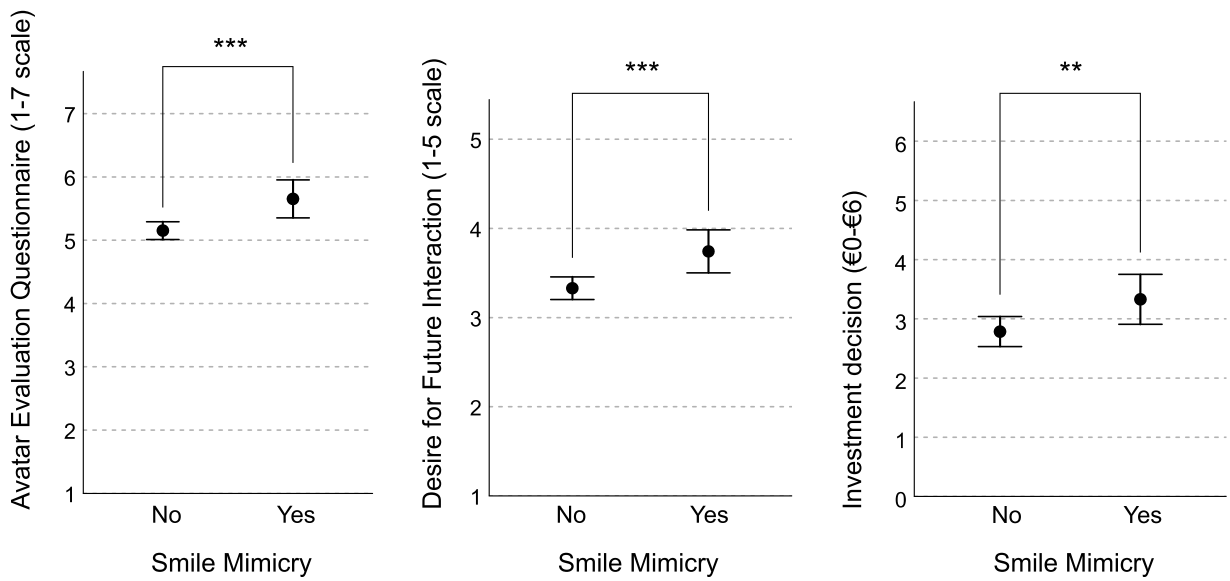

Fig. 4. Estimated Means with 95% Confidence Intervals of the Avatar Evaluation Questionnaire, Desire for Future Interaction, and Trust toward the Virtual Human Grouped by the Participant's Smile Mimicry Behavior.

Table 4
Results of the Virtual Human's Expression, Social Anxiety, and Their Interaction as the Fixed Effects.

Measures		Smile	Head Movements	Pupil Dilation	Blushing
Virtual Human's Expression	df	6086	5786	4483	6076
	F	2.479	.043	.455	.266
	p	.115	.835	.500	.606
Social Anxiety	df	6086	5786	4483	6076
	F	.034	.735	.261	1.194
	p	.854	.391	.610	.275
Interaction	df	6086	5786	4483	6076
	F	.133	.540	.718	.255
	p	.715	.463	.397	.613

confound was controlled because the participants were not instructed to do anything that required them to move their facial muscles. Moreover, in Krämer et al. (2013), the participants' smile data were averaged per condition and the timing when the smile occurred was disregarded. In our study, we only took smiles into account when they occurred within 8 s after the virtual human started to show an expression. Thus, we can be more certain that it was a smile mimicry response, hence, confirming that smile mimicry occurs in interactions with virtual humans.

As for the head movement behavior, our result indicates that people do not mimic the virtual human's head movements. There may be two alternative explanations for this finding. First, the virtual human's head wobble might appear less natural to the participants because only head nod and head shake are common head movements in western culture (Hadar et al., 1985). Second, mimicry may have been restricted to head nods: participants only showed a few head shakes and head wobbles. The follow-up analysis that only included head nods showed that the participants did not mimic the virtual human's head nod either. However, participants had fewer opportunities to mimic head nods compared to smiles, blushing, and pupil dilation. Future research may consider investigating head nod mimicry only, excluding the head shake and wobble so that there is enough power to detect head nod mimicry. Ultimately, more research needs to be conducted to investigate whether people mimic virtual humans' head nods or head movements. This is particularly relevant because of the growing number of studies investigating the effect of head nods or head movements being mimicked by the virtual humans (e.g., Aburumman et al., 2022; Bailenson and Yee, 2005; Hale and Hamilton, 2016; Vrijsen et al., 2010b). By studying whether people mimic these behaviors, we can further investigate whether both mimicking and being mimicked in terms of head movement behavior create rapport in interactions with virtual humans.

At the autonomic level, we did not find evidence for pupil dilation mimicry and blushing mimicry. For pupil dilation mimicry, there could be at least two reasons. First, a higher experimental control might be needed to investigate the effect. For example, previous studies always had an interstimulus interval that is completely different from the stimuli, e.g., a gray background (Fawcett et al., 2017; Harrison et al., 2006) or a scrambled image of the stimuli (Kret et al., 2015; Spicer et al., 2021). In our study, the virtual human's face and body were always there during the interstimulus interval, for at least 7 s before and after the pupil dilation onset. The participants could also see the virtual environment behind the virtual human i.e., the indoor room with a bookshelf and a desk. The only thing that changed was the pupil size of the virtual human. Therefore, the stimuli were less conspicuous compared to previous studies. Second, it has been argued recently that the choice of experimental tasks matters to study pupil dilation mimicry (Hartley and Reed, 2022). Hartley and Reed (2022) observed pupil dilation mimicry when the participants were instructed to judge whether the left or right pupil of the model in the photograph was larger, but not when they were instructed to judge the model's age in the same photographs. Their results suggest that more attention to the pupils' area may be needed to observe pupil dilation mimicry in the participants. Therefore, future research could try to replicate pupil mimicry studies using virtual humans but with a task that draws the participants' gaze more to the eyes, and additionally, to check whether the participants' eye gaze was drawn to the virtual humans' eye-region.

As for the blushing mimicry, because the blushing stimuli in our study were sudden onset, it may appear less natural as also commented by some of our participants. Moreover, we only had a response window of 12.5 s to measure the participant's blushing response, which may not be long enough to detect a response using a skin temperature thermistor on the cheek (Cooper et al., 2012; Drummond and Lim, 2000). Therefore, future research should consider programming the blush to appear gradually and prolong the response window for the skin temperature response. It is also worth mentioning that there is not much research that investigates how blushing is perceived by others (Kret, 2015), especially in the case of blushing mimicry. Shearn et al. (1999) showed evidence of blushing synchrony between performers and their friends (but not strangers) when watching videos of the performers singing but it was not clear whether the performer blushed on the video. A recent study showed a preliminary result of an increase in skin temperature in response to a blushing face (Folz et al., 2022). However, more research with stronger experimental control (e.g., with blood flow measurements or a longer baseline) is still needed to investigate whether blushing mimicry exists and, if it does, to what extent.

4.2. Social consequences of mimicry

For the second research question, our study showed that when the participants mimicked the virtual human's smile, the participants evaluated the virtual humans more positively, had more desire for future interaction, and trusted the virtual humans more. This result is in line with a previous study that indicated a positive effect of being mimicked, i.e., an increase in smiling by the participants when their smiles were mimicked by the virtual humans (Hoegen et al., 2018). Our result is also in line with the prosocial benefit of smile mimicry in human-human interaction (Chartrand and Bargh, 1999; Kulesza et al., 2015; McIntosh, 2006) which indicates that the prosocial benefit extends to an interaction with virtual humans.

Despite the positive association between mimicking the virtual human's smiles and liking and trust, we did not find any significant results for head movements, pupil dilation, and blushing mimicry. As far as we are aware, there is no prior research investigating the relationship between pupil dilation or blushing mimicry with liking and trust in interactions with virtual humans. However, for the head movement mimicry, even though previous research focused more on the effect of being mimicked, it is worth mentioning that the effect was not always positive. Bailenson and Yee (2005) found that the participants rated the virtual humans who mimicked their head movements as more persuasive and likable. However, Hale and Hamilton (2016) and Verberne et al. (2013) did not find any significant effects of head movement mimicry on trustworthiness. Factors such as manipulation detection and presentation might influence these results, as Bailenson et al. (2008) found that the participants trusted the virtual humans less when they detected that the virtual humans mimicked their head movements and Aburumman et al. (2022) found that the participants approached the mimicking virtual human more during a virtual maze task in which the head nod mimicry was programmed with naturalistic behavior rules. However, in the case of our study, it is more likely that we did not find any significant results of the three mimicry types due to insufficient power to analyze their relationship with liking and trust since we did not find evidence that the participants mimicked these three expressions in the first analysis.

4.3. Mimicry and social anxiety

For the third research question, we did not find evidence that social anxiety influences mimicry behavior. For the smile mimicry, the virtual humans only showed one type of smile that was shown randomly and did not take the story content into account, which might appear as polite smiles rather than smiles of pleasure to the participants. In that case, the finding is aligned with Heerey and Kring (2007) because they found that people with high social anxiety levels only show less mimicry in case of smiles of pleasure, but not polite smiles. However, both findings are in contrast with the finding by Dijk et al. (2018) that people with high social anxiety levels have an enhanced mimicry of polite smiles. Future research may benefit from adding different types of smiles as the stimuli or coding the participants' smile expressions more precisely by including polite smiles and smiles of pleasure. For the head movement mimicry, our result is not aligned with (Vrijsen et al., 2010a). We did not find that social anxiety influenced head movement mimicry, similarly, also not pupil dilation and blushing mimicry. These results may be explained by the scarcity of these types of mimicry in our sample. However, there could also be other methodological reasons that explain our result. First, the effects of social anxiety on behavior may be context-specific. For example, social anxiety has been found to affect the disclosure of personal information (Alden and Bieling, 1998) and gaze behavior (Chen et al., 2021) in situations implying a risk of negative social evaluation, but not in situations without such a risk. It may be that the interaction with our virtual humans is less threatening for the high socially anxious participants compared to previous studies which displayed the virtual humans in a head-mounted display (Vrijsen et al., 2010a) or had their participants interact with real humans (Abbott et al., 2018). Thus, participants in our study may have shown similar mimicry behavior regardless of their social anxiety levels because the situation implied less social-evaluative threat. This could be further investigated by systematically varying social-evaluative threat levels and assessing both state anxiety and mimicry in future studies. Second, previous studies (Abbott et al., 2018; Heerey and Kring, 2007; Vrijsen et al., 2010a) used pre-screening to select participants with high and low levels of social anxiety. In our study, we did not screen the participants beforehand and our sample contained fewer people with higher social anxiety levels. Thus, it might be the case that deviant behavior only occurs at higher levels of social anxiety.

5. Conclusions

In summary, the present study succeeded in studying different types of mimicry, its putative prosocial effects, and potential modulations by social anxiety by using virtual humans. This study also succeeded in combining some level of ecological validity with experimental control, which generalizes the previous mimicry findings especially the mimicry of smiles (Chartrand and Bargh, 1999; Dimberg et al., 2000; Hess and Bourgeois, 2010; Lundqvist and Dimberg, 1995). However, there are a few limitations in our study as discussed above. First, the participants only showed a few head shakes and wobbles which led to less power to investigate our research questions regarding head movements, and second, with our experimental design, we only allowed a short time to measure the participants' blushing response using the skin temperature sensor. Additionally, even though we have the desire for future interaction as the second measure for liking, the avatar evaluation questionnaire as a first measure only consisted of four questions. More questionnaires that measure liking, especially the ones that relate to the evaluation of virtual agents, could have been added. For future mimicry research in human-virtual human interaction, we propose a few main suggestions. First, to focus on head nod mimicry instead of all three head movement types. Second, to increase the experimental control to investigate autonomic mimicry in human-virtual human interaction. For example, the study of pupil size mimicry may benefit from a task that requires participants to focus on the eyes area. In addition, extended response times may be needed to study blushing mimicry, and blood flow measures may be considered. Third, to study smile mimicry further by adding smiles of pleasure in addition to polite smiles, especially to investigate the influence of social anxiety in mimicry. We also suggest assessing state anxiety felt by the participants when interacting with virtual humans and inviting more participants with high social anxiety levels to confirm whether deviant mimicry behavior only occurs at higher levels of social anxiety. Lastly, to consider providing a clearer interaction context in the experiment, such as preconditions so that participants seek affiliation with the virtual human (see Hess and Fischer, 2022). Even though in our study the participants mimicked the virtual human's smile without an interaction context, an affiliation goal may be needed to see a similar effect of the other mimicry types. Finally, we would like to summarize the practical implications of our key findings. First, we show that people mimic virtual humans' smiles, which confirms the findings by Krämer et al. (2013) by controlling for the participant's smile response timing. Second, we show that smile mimicry benefits the human-virtual human interaction in the party that is mimicking – which complements previous research that showed its benefit in the party that is being mimicked (Hoegen et al., 2018). These findings show that smile mimicry is a useful behavior in a human-virtual interaction that is associated with an increased liking and trust toward virtual humans, thus, smoothening human-virtual human interaction.

CRediT authorship contribution statement

Evania L. Fasya: Software, Validation, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft. **Esther van den Bos:** Conceptualization, Methodology, Investigation, Data curation, Supervision, Funding acquisition, Writing – review & editing. **Dirk K.J. Heylen:** Supervision, Funding acquisition, Writing – review & editing. **Mariska E. Kret:** Conceptualization, Methodology, Supervision, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

The data is available on https://dataverse.nl/dataverse/CogPsy

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijhcs.2023.103182.

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