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Eye contact during virtual storytelling: Enhancing social evaluation through pupil mimicry

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ABSTRACT

The human eye plays a crucial role in shaping social judgments; for instance, maintaining eye contact enhances social interactions and influences how others perceive us. At a more subtle level, the pupils also play an important role; recent research shows that pupil mimicry fosters trust. In our digitizing world, people frequently interact with virtual agents. Therefore, it is of crucial importance to investigate whether the positive effects of eye gaze and pupil mimicry generalize to virtual interactions. In the current study, we investigated whether eye contact and pupil dilation mimicry influence the evaluation of virtual humans and whether these effects vary with the participants' levels of social anxiety. Six virtual humans told a story which participants watched on a monitor screen. Three of them were programmed to mimic the participants' pupil size at moments when participants displayed natural pupil dilation, while the other three did not mimic these instances and instead, their pupil sizes dilated at random moments. After each story, we assessed how the virtual human was perceived by taking multiple social evaluation measures. The results show that the more the participants made eye contact, the more positively they evaluated the virtual human, especially during trials where the virtual humans mimicked the spontaneous instances of pupil dilation in participants' eyes. Social anxiety levels did not influence the results. This study demonstrates that the cumulative positive effects of eye contact and pupil dilation mimicry generalize to interactions with virtual agents, which may inspire potential applications.

1. Introduction

In our fast-paced globalized and digitized world, intricacies of emotion and nuanced communication often fade into the background. Consequently, there seems to be a surge in problems like loneliness, social isolation, and possibly social anxiety (i.e., persistent fears concerning embarrassment or being negatively evaluated in social situations, such as interactions or public performance (Heimberg et al., 1999)). As we increasingly interact through digital devices with other humans and virtual agents, incorporating subtle hinges of emotion into digital interactions may be crucial to preserving the quality of these social interactions. The eyes in particular play a crucial role in social interactions; maintaining eye contact (Bayliss and Tipper, 2006; Behrens and Kret, 2019; Mason et al., 2005) and observing pupil dilation influences our liking of and trust in interaction partners (Kret and De Dreu, 2019; Mattavelli et al., 2022). Previous research has shown that humans mimic others' pupil size (Fawcett et al., 2016; Harrison et al., 2006), and importantly, that pupil mimicry may promote trust in certain contexts (Kret et al., 2015; Prochazkova et al., 2018). Humans increasingly interact with virtual agents in domains such as healthcare or training systems (Kyrlitsias and Michael-Grigoriou, 2022). Therefore, implementing the functionality of eye contact and subtle emotional cues may help people to smoothly interact with virtual agents (Andrist et al., 2012; Tisserand et al., 2020). From a fundamental perspective, as virtual humans can show realistic expressions and social cues in an optimally controlled fashion, they can be used to investigate the effects of social signals that are difficult for humans to consciously control. In the current study, we investigated whether eye contact and pupil dilation mimicry affect people's social evaluations of virtual humans and whether the effects are influenced by social anxiety.

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Across human evolution, trust enabled humans to cooperate, form alliances, and build institutions (Henrich and Muthukrishna, 2021; Schilke et al., 2021). At the interpersonal level, trust is essential in various situations, such as hiring a new employee, consulting with a doctor, or choosing a romantic partner. In interactions with familiar others, reputation plays an important role. However, in interactions with strangers, nonverbal behaviors such as facial expressions or subtle signals in interaction partners' eyes are of pivotal importance (Campellone and Kring, 2013; Kret and De Dreu, 2019; Todorov et al., 2009). These allow us to quickly evaluate social partners and help us decide whether to trust them in the moment or in future interactions (Coan and Sbarra, 2015; van Kleef, 2016; Weiss et al., 2021).

The eyes are particularly salient and provide a rich source of information to observers in revealing intentions, attention, and emotion (Emery, 2000; Frischen et al., 2007; Kleinke, 1986). With the direction of gaze, one can infer someone's focus of attention (Ziman et al., 2023) which affects social evaluations. Direct gaze is associated with positive affect, although explicit social evaluation may be less consistently positive (Hietanen, 2018). Eye contact, i.e., when two persons look each other in the eyes, has been demonstrated to make partners come across as more trustworthy, likable, and attractive (Bayliss and Tipper, 2006; Kampe et al., 2001; Mason et al., 2005), transfer social messages (Mayrand et al., 2023), and foster various prosocial behaviors such as helping (Behrens and Kret, 2019; Manesi et al., 2016). In addition, pupil size may indicate social interest. Our pupils dilate in the dark, but also during arousal (Bradley et al., 2008). Previous research has shown that in a social context, pupil dilation may indicate discourse processing, sexual interest, or trust (Attard-Johnson et al., 2021; Kret and De Dreu, 2019; Zellin et al., 2011), and pupil constriction may indicate fatigue or boredom (Hopstaken et al., 2015; Unsworth and Robison, 2018). Not surprisingly then, pupil size plays an important role in social interactions.

Our social evaluation of other people is influenced by their pupil size. Previous research has demonstrated that people with large pupils are seen as more trustworthy, attractive, happy, and prosocial (Kret and De Dreu, 2019; Mattavelli et al., 2022). Conversely, people's pupil size can be influenced by their arousal, resulting from anticipated social interaction (Cheng et al., 2021) or emotional stimuli (Partala and Surakka, 2003). Interestingly, someone's pupil size can also be influenced by another's pupil size, specifically, someone's pupils may dilate upon seeing another's dilated pupils (Prochazkova and Kret, 2017). This phenomenon has been dubbed 'pupil mimicry', and has not only been observed in human adults (e.g., Harrison et al., 2006; Kret et al., 2015; Prochazkova et al., 2018) but also in infants (e.g., Fawcett et al., 2016) and great apes (Kret et al., 2014). In these studies, participants watched static images or short video clips showing only the cropped face or eye region of the partner, where the partner's pupils were either dilating, constricting, or static. The results showed that participants' pupils were larger when the partner's pupils were dilating compared to the other conditions, which indicates pupil dilation mimicry. Previous research showed that pupil mimicry does not only indicate shared attention (Kang and Wheatley, 2017) but also influences social evaluation (Kret et al., 2015; Prochazkova et al., 2018). Studies that investigated pupil dilation mimicry's association with social evaluation showed that the participants trusted a virtual partner in a trust game more when they mimicked the partner's pupil size (Kret et al., 2015; Prochazkova et al., 2018). In these studies, researchers manipulated the pupil size of the stimulus and investigated participants' reactions. However, pupil mimicry in real life presumably occurs in an interactive exchange between interaction partners. One first step in understanding this relationship better, yet in a controlled way, is to investigate whether the positive social effect of pupil mimicry is present for the mimickee, in other words, the person who is being mimicked. Another outstanding question is whether pupil mimicry is bound to the artificial eye slits previous research used, or occurs in more natural situations.

In our rapidly digitizing world, artificial agents such as robots and virtual agents are developed to interact with humans in various domains such as education, healthcare, or training systems (Belpaeme et al., 2018; Kyrlitsias and Michael-Grigoriou, 2022). These agents need to be perceived as trustworthy in order to be accepted and establish successful cooperation with humans (de Melo et al., 2019; Philip et al., 2020). Humanlike nonverbal behaviors such as eye contact and even subtle emotional cues such as pupil dilation may help to make them appear prosocial and trustworthy. Thus, computer scientists have been developing virtual humans or robots with the functionality of eye contact (e.g., Bérard et al., 2016; Duchowski et al., 2015; see a review by Ruhland et al., 2015) and facial expressions reflecting involuntary physiological responses such as pupil dilation, blushing, sweating, and tears (Jörg et al., 2018; Sejima et al., 2017; Tisserand et al., 2020). Eye contact behaviors in these artificial agents enhance our interaction experience with them in terms of conversation quality (Garau et al., 2001; Heylen et al., 2002; Rogers et al., 2022), liking (Andrist et al., 2012; Huang et al., 2011; Xue et al., 2022), and trust (Normoyle et al., 2013). Expressions of physiological responses have also been found to increase our perception of the intensity and accuracy of the emotions conveyed by the virtual agent (de Melo et al., 2010; Dong et al., 2022). A recent study investigated the effect of pupil dilation mimicry for the mimickee using a robot consisting of a pair of eyes (Sejima et al., 2024). It showed that the robot with pupil mimicry behavior was liked more by the participants compared to the robot showing random or no pupil dilation. However, they used an indirect approach to measure the participants' pupil size, i.e., by inferring pupil dilation from the participant's speech utterance bursts instead of using an eye-tracking device. Collectively, these results suggest that the social effect of eye contact and expressions of physiological responses may extend to interactions between humans and artificial agents, and that a more systematic investigation, e.g., by using an eye-tracking device to measure pupil dilation, could strengthen these previous results.

Virtual humans, in particular, have been shown useful in practical applications, such as skills training and healthcare (Cui and Liu, 2023; Xie et al., 2021). On the other hand, they can also be beneficial for fundamental research in social science (Bente et al., 2001; Blascovich et al., 2002; Pan and Hamilton, 2018). Compared to studies using human confederates and photos or videos of actors, virtual humans allow for a more controlled research design while maintaining a decent level of ecological validity in investigating the effect of being mimicked (e.g., Bailenson and Yee, 2005; Vrijsen et al., 2010b). Research using virtual humans can provide answers to unique research questions that are impossible to answer by studying real-life interactions, providing the potential to investigate the effects of subtle emotional cues and what it means to be mimicked on such subtle, unconscious levels as pupil dilation.

In addition to providing insight into these effects in the general population, such research provides the opportunity to examine the processing of emotional information in specific subgroups. For example, there are some indications that interacting with virtual humans is appealing to socially anxious people. Previous research has shown that they are more inclined to share personal information through computer-mediated communication than in a face-to-face conversation (Kang and Gratch, 2010; Lucas et al., 2014; Stritzke et al., 2004). However, one factor underlying this preference seems to be the invisibility of their own nonverbal cues (Schouten et al., 2007), easing their fear of being scrutinized. In face-to-face social interaction, people with higher levels of social anxiety showed reduced eye contact (Chen et al., 2023) or heightened physiological arousal when they made eye contact (Rösler et al., 2021). When asked to observe virtual humans with either a direct or an averted gaze, highly socially anxious individuals spend less time observing those with a direct gaze (Raimbaud et al., 2022). An earlier study on the evaluation of virtual humans showed that socially anxious people perceived them overall as equally likable as people without anxiety issues but they evaluated virtual humans that mimicked their head movements less positively than low socially anxious people

(Vrijsen et al., 2010b). Hence, subtle emotional cues may have a different influence on socially anxious individuals' evaluations of virtual humans.

In this study, we investigated the effects of eye contact and pupil dilation mimicry on the evaluation of virtual humans, and whether social anxiety influences the relationship between them. Participants each watched six virtual humans with a direct gaze telling a story. Three of the virtual humans mimicked the participant's pupil dilation, whereas the other three did not. With this design, we aimed to answer two research questions. First, is the participants' gaze at the virtual humans' eyes and their pupil dilation being mimicked by the virtual humans positively associated with the participants' social evaluation of the virtual humans? Second, does social anxiety modulate the aforementioned relationships? Based on the literature above, we hypothesize that eye contact and pupil dilation mimicry are positively associated with social evaluation. However, we took an exploratory approach to the possible modulation by social anxiety as there was no previous research investigating this effect.

2. Materials and methods

2.1. Participants

There were 117 participants in the study. Due to technical problems, the final sample consisted of 115 participants (66 female), with an age range of 17 to 38 ($M = 21.97$; $SD = 3.83$). Most of them were university students and were recruited via SONA participant management and recruitment software. As compensation, participants could choose to receive student participation credits or a monetary reward of €6.50. In addition, they could win a bonus of a maximum of €2.50 depending on their decisions during the trust game. The study was approved by the local ethics committee (CEP18–0714/302) and pre-registered on aspredicted.org (number 61869). The research motivation, methods, and statistical analysis were conducted as planned in the preregistration, except for the eye contact variable which was added at a later phase during the research.

2.2. Stimuli

Stimulus materials consisted of animation displays of six virtual humans (three female and three male appearances; see Supplementary 1 for the appearance of all virtual humans) telling a story from a virtual indoor room with a bookcase and a desk in the background (see Fig. 1C). The virtual humans were 3D humanoid models created with Morph Character System version 1.6. Unity version 2018.2.2f1 was used to develop the experiment.

2.2.1. Speech

In each trial, the virtual human was telling a story. Audio recordings from Fasya et al. (2024) were used, which consisted of six different stories provided by three female and three male speakers ranging in duration from 2:17 to 2:28 min. The stories were about life events that did not induce strong emotional reactions (as investigated in the pilot study on Fasya et al., 2024). We wanted to minimize the possibly confounding effect of story content on the social evaluation score, to better estimate the effects of eye contact and pupil dilation mimicry. The stories provided by the male speakers were about a photography hobby, having pets, and a childhood experience. The stories provided by the female speakers were about a dance hobby, watching movies, and moving to a new place. In the experiment, the stories were randomly assigned to the 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. Two versions of each story, one Dutch and one English, were recorded from the same speaker. 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 corresponding to the syllables. This process results in 12 LipSync files (2 languages x 6 audio files).

2.2.2. Eyes

The virtual humans faced the participants with a direct gaze. They all had green eyes and were equipped with a pupil dilation blendshape (a function that enables changes in pupil size). The pupil dilation animation was prepared as follows. The pupils dilated over a period of 4 s; in the first second the pupils increased from normal to maximum size, in the next two seconds they were stable at the maximum size, and in the last second they decreased back to the normal size (see Fig. 1D). The four-second duration was chosen because it is the most common duration where muscle response or electrical activity of the muscle response is observed in the facial-mimicry literature (Kret et al., 2015). The one-second duration was chosen for the pupils to increase or decrease, so that the time when pupils are stable at maximum size is longer (2 s) than the time for them to increase/decrease (1 s), thus increasing the salience of dilated pupils. Pupil dilation in virtual humans might look more conspicuous than real human's pupil dilation, but the same pupil dilation animation is used in both the mimicking and the non-mimicking conditions to avoid confounding. In the mimicking condition, the virtual humans' pupils dilated only if the participant's pupils dilated. Thus, the pupil dilation animation was controlled by using a custom script. In the non-mimicry condition, the virtual humans' pupils were programmed to dilate at two or three predetermined time points per trial. In this case, the pupil dilation animation was attached to the LipSync files. This process results in a total of 24 LipSync files being used in the experiment program (2 conditions x 2 languages x 6 audio files). One story in the non-mimicry condition showed no pupil dilation events because of a technical issue but we retained this trial because a participant might also show no pupil dilation during the mimicry condition, which means that the virtual human would also show no pupil dilations (see Supplementary 2 for the frequency of virtual humans' and participants' pupil dilations).

In addition to the pupil dilation animation and the mouth movements, the virtual humans were also equipped with a standing-idle animation, an eye squint and eye-brow raise animations to make them appear more natural. The standing-idle animation was controlled by the Unity animation controller, while the eye squint and eye-brow raise animations were added to the LipSync files and were displayed several times during the storytelling.

2.3. Procedure

Participants were seated in a laboratory room in front of a desk with a 23.8″ monitor display placed on it. The brightness of the monitor screen was kept constant at 75 % across all participants to reduce its influence on their pupil dilation behavior. 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. Afterward, they filled in a social anxiety questionnaire, read trust game instructions, and answered a few practice questions about the trust game. In the trust game instruction, the participants were told that each virtual human was a representation of a real human who had indicated in the past how much they would like to return the investment (see the detailed instruction in the Measures section). Besides this prior information, the participants were not given any more details about the nature of the virtual human. Next, the participants put on headphones, the height of the monitor was adjusted so that the participants' gaze was in the center of the monitor display, and a 6-point eye-tracking calibration was performed. When the calibration was acceptable, the computer task began (see Fig. 1A).

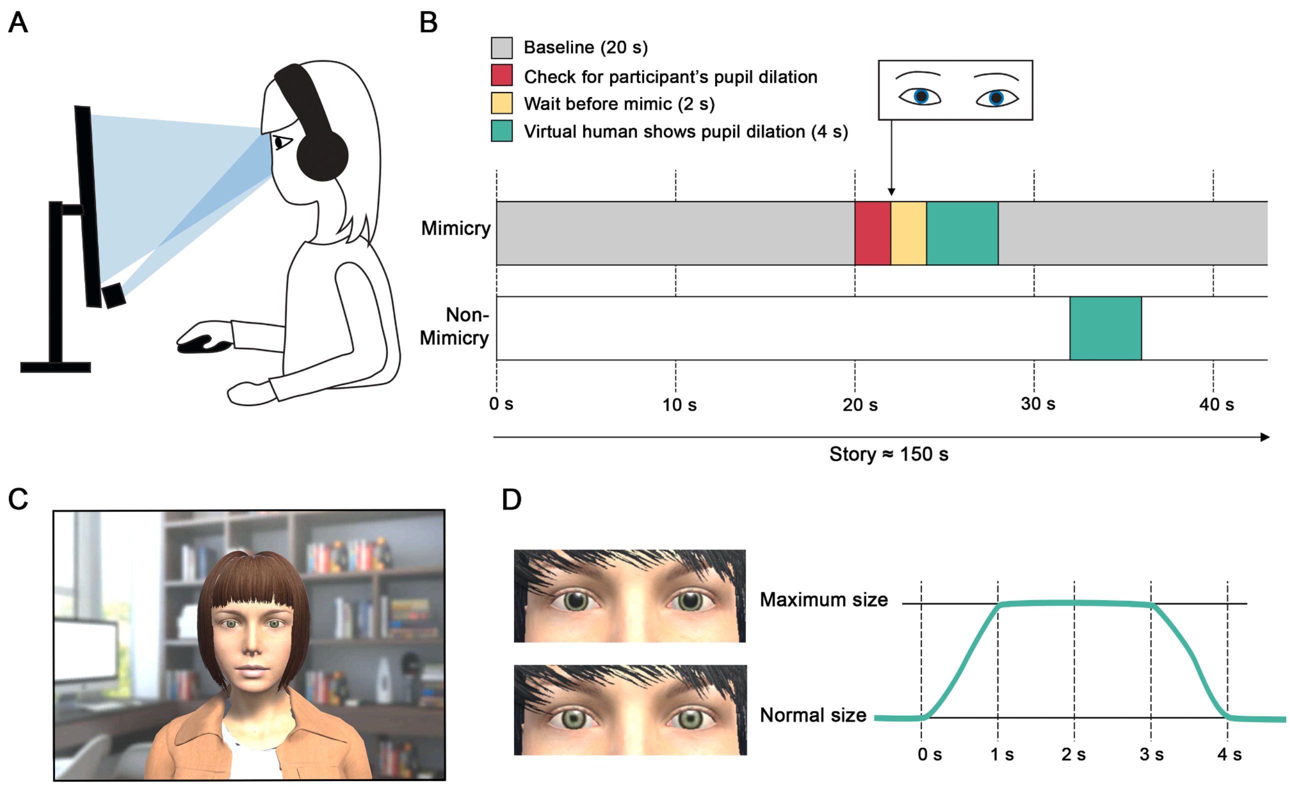

Fig. 1. The stimuli. *Note.* A: Participants watched virtual humans via a monitor display with an eye tracker mounted underneath. They listened to the stories using headphones and answered the questionnaires using a computer mouse. B: The timeline of a mimicry and a non-mimicry trial. In the mimicry condition, if the participant showed pupil dilation, the virtual human responded by showing pupil dilation after a 2-second delay. In the non-mimicry condition, the virtual human showed pupil dilation at a predetermined randomized time regardless of the participant's pupil size behavior. C: An example of a virtual human that was displayed to the participant. D: A virtual human's pupil dilation event. Pupil size increased from normal to maximum size in the first second, was stable at maximum size for two seconds, and decreased back to normal size in the last second.

Once the computer task started, the participants were presented with a virtual human on the monitor display (see supplementary video). The virtual human was visible from the chest and above (see Fig. 1C). The participants listened to the story that was told by the virtual human via the headphones. At the end of each trial, they completed two questionnaires on their evaluation of and the desire for future interaction with the virtual human and selected an investment decision for the trust game using the mouse on the desk. They also answered a dual-choice question about the topic of the story. The experiment consisted of six trials, each with a different virtual human and a different story. The virtual humans' order was randomized. The experiment's mimicry condition was within-subject with a counterbalanced block design; the first three trials had one mimicry condition and the last three had the other condition. At the end of the experiment, we asked whether the participants noticed that the virtual human mimicked their behaviors and, if so, what the behavior was. None of the participants guessed that the virtual human mimicked their pupil dilation, but many reported that they noticed pupil dilation upon subsequently being informed. The participants were fully debriefed and asked to pick a random trial number on which their trust game bonus was based. Each session lasted approximately 45 min.

2.4. Measures

2.4.1. Social anxiety

Social anxiety was measured using the Liebowitz Social Anxiety Scale Self-Report Questionnaire (LSAS-SR; Liebowitz, 1987). In previous research, the LSAS-SR had an excellent internal consistency ($\alpha = 0.96$; Heimberg et al., 1999). The Cronbach's alpha in our sample also indicated a high level of internal consistency $\alpha = 0.929$ (English $\alpha = 0.927$; Dutch $\alpha = 0.942$). 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). Participants 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' total fear and total avoidance scores were summed (the maximum possible score was 144). Two participants did not answer one to two 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. Participants' mean social anxiety score was 42.11, with a standard deviation of 19.79 (see Supplementary 3 for the distribution plot).

2.4.2. Eye contact

Participants' eyes were tracked using a Tobii X2–60 (sampling rate 60 Hz; $n = 31$ participants) and a Tobii X3–120 (sampling rate 120 Hz; $n = 84$ participants). Both eye-trackers detected the participant's eyes in a similar way (additional analysis showed that eye-tracker type was not a significant predictor for the pupil dilation frequency: χ^2 (1) = 0.002, $p = .962$). The Tobii Pro Software Development Kit (SDK) for Unity v1.6 was used to access the eye gaze data in the experiment program and Tobii Pro Eyetracker Manager v1.9.0 was used to perform the participant's eyes calibration. Participants' invalid gaze samples (defined by Tobii), which counted for 26.11 % of the total samples, were excluded from the dataset (n = 2707,194 out of 10,368,031). Following standard procedures, we also excluded trials where >50 % of the data was missing (n = 98 trials) and participants if >50 % of their data was missing or invalid (n = 13 participants). The final dataset resulted in 7189,083 eye gaze samples (69.34 % of the total samples).

An Area of Interest (AOI) was defined around the virtual human's eyes (see Fig. 2A). The percentage of participants' valid gaze samples within a trial that was on the AOI was computed as a dwell time measure of eye contact, including all fixations and saccades within the AOI (Tullis and Albert, 2013). The number of gaze samples on the AOI was derived from the number of hits on 3D colliders attached to the 3D virtual human models that contained the relevant parts of the virtual human's body on the first trial (see Supplementary 4). These colliders were also prepared for the mouth, body, and background, but in the dataset, we summarized them into the eyes, face (excluding the eyes), and others (all areas on the screen except for the eyes and the face). Participants mostly looked at the eyes (M = 48.51 %; SD = 24.99), followed by other parts of the face (M = 29.27 %; SD = 19.91), or other parts of the screen (M = 22.22 %; SD = 25.34) (see Fig. 2B for the plot of participants gaze across all trials and see Supplementary 5 for an overview of participants' gaze during virtual human's pupil dilation mimicry events). We took the percentage of gaze samples at the virtual human's eyes per trial for the analysis.

2.4.3. Pupil dilation mimicry

In the mimicking condition, the virtual human showed pupil dilation in response to the spontaneously dilating pupil sizes of participants. Pupil dilation was computed and defined per participant. Specifically, we established personal baselines for pupil size and pupil size changes by storing their independent values during the first 20 s of a trial. The 20-second duration was chosen to allow at least one to two mimicry events to occur per minute, aligned with the frequency of a behavior that the participants mimicked in previous literature (van Baaren et al., 2006; Vrijsen et al., 2010a). During this time, the participants' pupil size was registered and stored 60 times per second. The participants' pupil size changes compared to the previous time point were also computed and stored 60 times per second. We calculated the mean and the standard deviation of these stored pupil sizes and pupil size changes as the baseline. The threshold for pupil dilation was defined as the baseline pupil size mean plus two times the standard deviation and the pupil size change mean plus two times the standard deviation. After the baseline time, if the participant's pupil size and pupil size change were found to be larger than the threshold, the virtual human would show a pupil dilation after a 2-second delay. During the 2-second delay, the program did not observe the participant's pupil size anymore. We opted for this delay as in previous pupil mimicry research (Kret et al., 2015; Prochazkova et al., 2018), participants mimicked the pupil size changes seen in stimuli after 2 s. Before those 2 s, participants' pupil sizes are still recovering from a light reflex or orienting response. Thus, we imitate this observed real-life pupil dilation mimicry situation in the mimicry behavior that the virtual human had. After the virtual human showed pupil dilation, we calculated a new 20-second baseline (see Fig. 1B).

We excluded participants from the analysis if they did not show sufficient pupil size variation so that there were no moments where their pupil sizes dilated (n = 15 participants). In total, the virtual humans showed 25 % more instances of pupil dilation in the non-mimicry condition (n = 584) than in the mimicry condition (n = 439) but on average, the virtual humans and the participants had a similar number of pupil dilation instances. Specifically, in the non-mimicry and mimicry trials respectively, virtual humans displayed 0 to 3 (M = 1.947; SD = 1.033) and 0 to 5 (M = 1.463; SD = 1.27) pupil dilation instances per trial, while the participants showed 0 to 5 (M = 1.51; SD = 1.292) and 0 to 6 (M = 1.493; SD = 1.305) instances of pupil dilation (see Supplementary 2 for additional statistics).

2.4.4. Social evaluation score

A social evaluation score assessing how virtual humans were perceived was composed of three different measures: the Avatar Evaluation Questionnaire (AEQ; Vrijsen et al., 2010b); the Desire for Future Interaction Scale (DFI; Blöte et al., 2012 adapted from Coyne, 1976); and the Trust Game (TG; Fasya et al., 2024 adapted from Kret et al., 2015).

The AEQ 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 (Cronbach's α = 0.91; Vrijsen et al., 2010b). Ratings of negative impressions were reverse-coded before computing the average score. The questionnaire was answered on a 7-point Likert scale (1 = not at all; 7 = very much), and its Dutch version was translated by a Dutch native speaker. The Cronbach's alpha for this study's sample indicated a high level of internal consistency α = 0.908 (English version α = 0.902; Dutch version α = 0.921). The participant's answers were averaged per trial (M = 4.96; SD = 1.27).

The DFI consisted of seven questions: would the participant be willing to meet the speaker in real life, work on a project with the speaker, sit with the speaker on a three-hour bus ride, invite the speaker

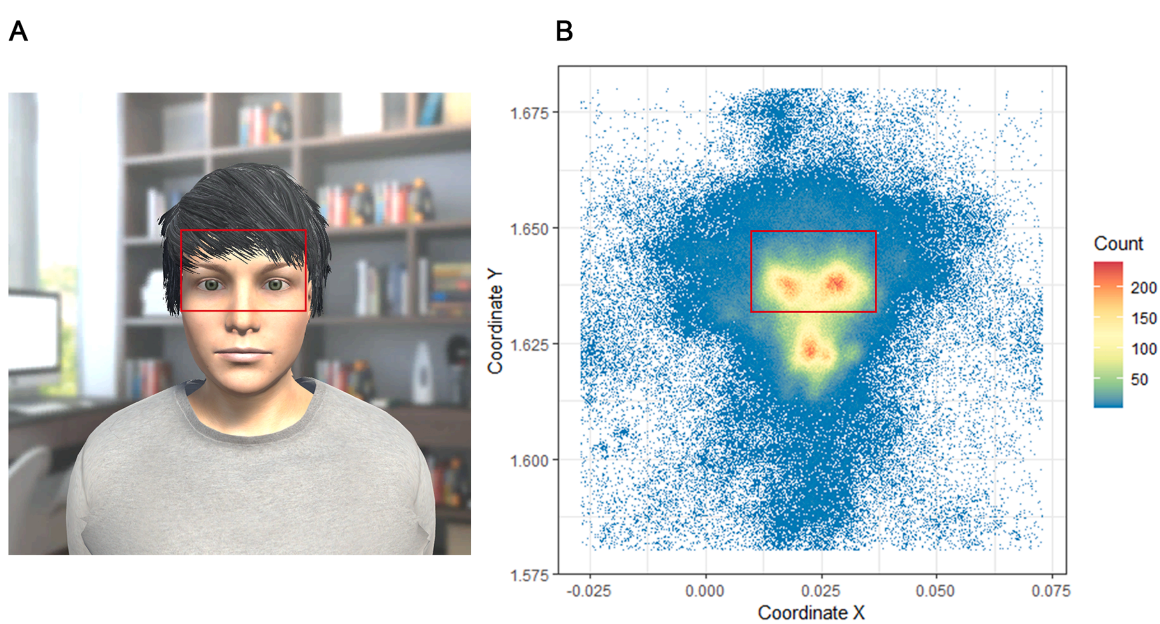

Fig. 2. The area of interest. *Note*. The red rectangle represents the area of interest (AOI), which is the eye area of the virtual human. A shows the AOI on a virtual human displayed to the participants and B shows the AOI on the plot of actual participants' gaze across all trials.

to his/her home, get to know the speaker better, seek advice from the speaker, and sit next to the speaker in class (Cronbach's α = 0.93; Blöte et al., 2012). The questionnaire was answered on a 5-point Likert scale (1 = definitely not; 5 = definitely). The Cronbach's alpha for this study's sample indicated a high level of internal consistency α = 0.921 (English version α = 0.917; Dutch version α = 0.931). The participant's answers were also averaged per trial ($M = 3.24$; $SD = 0.97$).

The TG aims to have the participant assume that a partner would return more money if the participant invested money, thus, the participant needs to trust the virtual human more to invest more money in them. The participant played the TG with every virtual storyteller. Thus, after each trial, they made an investment decision and decided on an amount ranging from €0 to €6. The instruction followed similar procedures as in Fasya et al. (2024) and the protocol was not viewed as deceptive by the ethics board. They were told at the beginning of the experiment that there was a real person represented by the virtual human and that 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 €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. The participants were asked how much they would like to invest in the virtual human at the end of every trial. 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 (ranging from €0 to €2.5). We excluded participants if they always invested the same amount across the six trials ($n = 9$ out of 115) since they might not base their judgment on their trust intuition on the virtual human but rather on a generalized strategy of a higher chance of getting a bonus. For those participants who did not vary their investments at all, we based our social evaluation measure on the AEQ and DFI exclusively, on which they did show variance. There was one TG score per trial per participant ($M = 2.98$; $SD = 1.65$).

Our participants' evaluations of the virtual humans were comparable to previous research (Fasya et al., 2024: AEQ: $M = 5.21$; $SD = 1.15$, DFI: $M = 3.37$; $SD = 0.93$, TG: $M = 2.86$; $SD = 2.58$).

2.5. Statistical analysis

Preliminary analyses were conducted to determine whether the three social evaluation measures could be combined (based on the preregistered plan), to verify that social anxiety was not directly related to social evaluation of the virtual human and to examine whether eye-contact was related to social anxiety.

In the first main analysis, to investigate the relationship between eye contact and pupil dilation mimicry on the evaluation of virtual humans, we ran linear mixed modes with the social evaluation scores (3 evaluations), nested in trials (3 trials), nested in mimicry condition (2 conditions), and nested within subjects (87 subjects) as the multilevel structure. The dependent variable was the social evaluation score and the main predictors were the following variables added one by one to the model: eye contact (level-2), mimicry (level-3), and eye contact x mimicry (cross-level interaction). We added trial order and story as control variables since they improved the model fit [trial order: $\chi^2(2) = 10.998$, $p = .004$; story: $\chi^2(5) = 47.280$, $p < .001$]. Story was also added as a random effect to account for its variability across participants. We also checked whether the virtual human's pupil dilation frequency affects the participants' evaluations of the virtual humans but it did not [$\chi^2(1) = 0.998$, $p = .318$] so we did not add it as a control variable.

In the second main analysis, we investigated whether social anxiety modulated the effect of eye contact and mimicry on the social evaluation scores. We ran the same models as in the first analysis (including the control and random variables) and added the following predictors one by one to the model: social anxiety (level-4), social anxiety x eye contact, and social anxiety x mimicry (cross-level interactions).

All statistical models were run using lme4 package v1.1.35.1 in R v4.2.1 with bobyqa as the optimizer model. See Table 1 for the detailed model comparison results for the main analyses.

3. Results

3.1. Preliminary analyses

We conducted a preliminary analysis to examine the correlations of each measure of the social evaluation score. The results showed that AEQ and DFI were highly positively correlated [$r(499) = 0.82$, $p < .001$] and that AEQ and DFI were moderately positively correlated with TG [AEQ: $r(457) = 0.59$, $p < .001$; DFI: $r(457) = 0.56$, $p < .001$]. Since all three outcome variables significantly correlated with each other, we combined them by transforming them into z-scores and collating them in a long data format in the dataset. Combining measures has the advantage of protecting against the inflation of Type I error that would result from testing the same hypothesis three times on separate measures.

Secondly, we conducted control analyses to verify whether social anxiety influenced the overall evaluation of the virtual human and whether it was associated with possible diminished eye contact. To test the first, we conducted a linear mixed model analysis with social evaluation scores (3 evaluations), nested in trials (3 trials), nested in mimicry condition (2 conditions), and nested within subjects (87 subjects) as the multilevel structure. To check its possible relationship with diminished eye contact, linear mixed model analysis was run with trials (6 trials) nested within subjects (87 subjects) as the multilevel structure. In both of these analyses, we compared an intercept-only model with another model where social anxiety was added as the predictor. A random intercept for each individual was included in both models. The dependent variable for the first analysis was the social evaluation scores, while for the second one was the eye contact. From the results, we verified that in line with previous research (Vrijsen et al., 2010b), social anxiety played no role in the overall evaluation of virtual humans [$\chi^2(1) = 0.006$, $p = .940$; $EM < 0.001$; $SE = 0.003$; 95 % CI [−0.005, 0.005]] and was also not related to the duration of eye contact in these virtual interactions [$\chi^2(1) = 0.494$, $p = .482$; $EM = 0.085$; $SE = 0.122$; 95 % CI [−0.154, 0.323]].

3.2. Main analyses

A main effect of eye contact on social evaluation score [$\chi^2(1) = 19.151$, $p < .001$] underlines the importance of eye contact during social interactions. As shown here, looking at a virtual human in the eye more is associated with more positive social evaluation (standardized coefficient of β = 0.12, indicating a small effect size; see Table 2 for the estimated means). The significant positive relation with eye contact was also found for each individual measure of social evaluation when they were analyzed separately (see Supplementary 6). This key result extends previous work that demonstrated such positive effects on person perception during real interactions (Bayliss and Tipper, 2006; Kampe et al., 2001; Mason et al., 2005). Mimicry did not influence the evaluation of the virtual humans [$\chi^2(1) = 0.684$, $p = .408$]. However, a significant interaction between eye contact and mimicry [$\chi^2(1) = 6.599$, $p = .010$] shows that when more eye contact was made, mimicry

Table 1
Model comparison results for the main analyses.

Model Specifications			Model Fit			Likelihood Ratio Test		
Model	Simpler Model	Effects Added	AIC	BIC	LL	df	X^2	p
A	–	Intercept	3968.5	3984.3	−1981.2	–	–	–
B	A	Trial order	3961.5	3987.9	−1975.7	2	10.998	.004
C	B	Story	3924.2	3977.1	−1952.1	5	47.280	<.001
D	C	Story (Random)	3477.6	3636.3	−1708.8	20	486.536	<.001
E	D	Eye contact	3460.5	3624.4	−1699.2	1	19.151	<.001
F	E	Mimicry	3461.8	3631.0	−1698.9	1	0.684	.408
G	F	Eye contact x Mimicry	3457.2	3631.7	−1695.6	1	6.599	.010
H	G	Social anxiety	3459.2	3639.0	−1695.6	1	0.008	.930
I	H	Social anxiety x Eye contact	3460.6	3645.6	−1695.3	1	0.607	.436
J	I	Social anxiety x Mimicry	3462.5	3652.9	−1695.3	1	0.058	.810

Note. Intercept within individuals was always included as a random factor in all models. Story within individuals was added as a random factor in model D to J.

Table 2
Fixed effects estimates of the first and second main analysis models.

Fixed Effects	Estimate	Standard Error	95 % Confidence Interval	
			Lower	Upper
First Main Analysis Model				
Eye contact	**0.005**	**0.002**	**0.000**	**0.009**
Mimicry	−0.390	0.142	−0.677	−0.104
Eye contact x Mimicry	**0.007**	**0.003**	**0.002**	**0.012**
Second Main Analysis Model				
Social anxiety	0.084	0.116	−0.152	0.320
Social anxiety x Eye contact	−0.001	0.002	−0.005	0.002
Social anxiety x Mimicry	−0.015	0.067	−0.150	0.119

Note. The text in bold indicates significant effects. The first main analysis model refers to model G in Table 1: social evaluation scores ~ trial order + story + eye contact + mimicry condition + eye contact * mimicry condition + (story | subjects). The second main analysis model refers to model J in Table 1: social evaluation scores ~ trial order + story + eye contact + mimicry condition + eye contact * mimicry condition + social anxiety + social anxiety * eye contact + social anxiety * mimicry condition + (story | subjects).

significantly increased the social evaluation score (β = 0.17, indicating a small effect size; see Fig. 3 for the plot). The separate analyses for each social evaluation measure showed that this interaction effect was

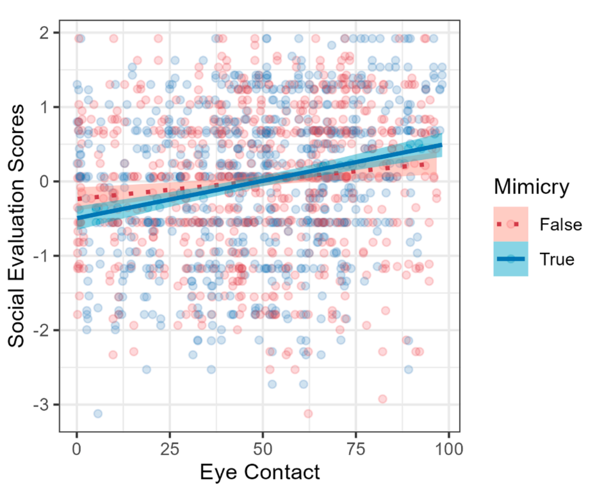

Fig. 3. The relationship of eye contact and pupil dilation mimicry with the social evaluation scores. *Note*. The X-axis shows the participants' percentage of gaze samples (0–100 %) on the Area of Interest (AOI) containing the virtual human's eyes. The Y-axis shows the standardized scores on the Avatar Evaluation Questionnaire, Desire for Future Interaction Scale, and Trust Game. The interaction between eye contact and mimicry was significant, which suggests that participants evaluated the virtual humans more positively when they made more eye contact with those who mimicked their pupil dilation.

associated with the desire for future interaction scores (see Supplementary 6). Furthermore, additional analyses showed that the social evaluation score difference between the two mimicry conditions was significant in participants with high eye contact [$\chi^2(1) = 15.637$, $p <$ .001] but not in low or medium eye contact groups. This suggests that pupil dilation mimicry mattered for social evaluation when eye contact intensity was high (see Supplementary 7). See Supplementary 8 for an analysis supporting the interpretation that mimicry was conditional upon eye contact instead of eye contact being enhanced by mimicry.

Then, in order to investigate whether social anxiety did play a role during the above-described effect where pupil mimicry impacted social evaluation during instances of eye contact, we added social anxiety scores to the first main analysis model. The results show that social anxiety level did not modulate any of the previously described effects [in modulation with eye contact: $\chi^2(1) = 0.607$, $p = .436$; and pupil mimicry: $\chi^2(1) = 0.058$, $p = .810$] (see Table 2 for the estimates). Thus, while social anxiety plays an important role in real-life interactions with true persons, socially anxious people may be free from these issues during virtual interactions.

4. Discussion

The eyes provide a rich source of information during social interactions (Emery, 2000; Frischen et al., 2007; Kleinke, 1986). Subtle eye cues have been found to facilitate mutual understanding and trust (Kret and De Dreu, 2019; Zellin et al., 2011). The current study investigates whether eye contact and pupil dilation mimicry influence how virtual humans are evaluated and whether social anxiety modulates this relationship. The results show that more eye contact with a virtual human is associated with more positive social evaluation. This positive relation was further boosted when the virtual human mimicked the participant's pupil dilation. Further, social anxiety did not modulate the relationship between eye contact or pupil dilation mimicry and social evaluation. We discuss these key findings in more detail below.

The importance of eye contact in social interaction has been underlined by many researchers (Emery, 2000; Frischen et al., 2007; Kleinke, 1986). Using virtual humans that tell a story to the participants, we found a main effect of eye contact on the social evaluation of the virtual humans. Specifically, participants' social evaluations of the virtual human were more positive when they looked more at the virtual human's eyes. This result is aligned with previous research showing that humans with direct gaze are evaluated more positively (Kampe et al., 2001; Mason et al., 2005), and induce more cooperative behavior (Behrens and Kret, 2019; Manesi et al., 2016) and trust (Bayliss and Tipper, 2006). We show that this positive effect also extends to interactions with virtual humans, complementing previous studies (e.g., Andrist et al., 2012; Normoyle et al., 2013; Rogers et al., 2022). Our study shows that the social evaluation of virtual humans as interaction partners is not only enhanced by the virtual humans' direct gaze but also by the participant looking at the virtual humans' eyes.

Moreover, we found a significant interaction effect between eye contact and pupil dilation mimicry on social evaluation; the participants evaluated the virtual humans more positively when they looked at the eyes of those who mimicked their pupil dilation. Aligned with previous results (Kret et al., 2015; Prochazkova et al., 2018), the current study shows that the positive effect is not only linked to mimicking but also an effect of being mimicked. Our result also extends the study by Sejima et al. (2024) by using a direct approach to detect participants' pupil dilation, i.e., using an eye tracker rather than estimating it from speech behavior. Moreover, compared to the previous studies (Kret et al., 2015; Prochazkova et al., 2018; Sejima et al., 2024), our result generalizes the pupil mimicry effect on social evaluations to a more natural setting. The fact that pupils were still perceived by the participants in such rich stimuli with a lot more information, including a whole face, dynamic expressions, and stories, suggests that pupil dilation mimicry plays a small but important role in social evaluation.

We did not find evidence that social anxiety influences the relationship between eye contact and social evaluations. However, it is important to note that we did not find any relationship between social anxiety and diminished eye contact either, which is in contrast with some previous studies involving conversations between two humans (Chen et al., 2023) and passive viewing of a virtual audience (Raimbaud et al., 2022). In relation to the latter study, their participants were asked to observe an audience consisting of several virtual humans, each of which showed either a direct or an averted gaze toward the participants. Although the participant did not speak, perhaps the stimuli still represented a situation where the participant felt exposed to others. It has been suggested that socially anxious people from a non-clinical sample like ours only show diminished eye contact when there is a risk of negative social evaluation (Chen et al., 2023; Rösler et al., 2021). In line with this suggestion, diminished eye contact has been observed at the beginning of a conversation with a stranger (Haensel et al., 2020) and when the socially anxious person was speaking rather than listening (Baker and Edelmann, 2002; Haensel et al., 2020). Further research will have to show whether socially anxious people make less eye contact with virtual humans when they have to do the talking or feel safe with virtual humans in general. The latter may be good news for more socially anxious people who have to interact with virtual humans in education, health care, or training systems. However, if similar findings are obtained for people with social anxiety disorder, this may imply limits on the role of exposure to virtual humans in treatment.

Regarding mimicry, our result shows that social anxiety did not influence participants' social evaluation of virtual humans that mimicked their pupil dilations. This suggests that socially anxious individuals do not show altered person perception when their pupil dilations are mimicked. However, more research is needed to replicate this result since as far as we are aware, no other research has been conducted to investigate this. Furthermore, the way socially anxious individuals are mimicked seemed to play a role in the social evaluation, as shown by studies using virtual humans. Highly socially anxious people evaluated virtual humans that mimicked their head movements less positively than low socially anxious people (Vrijsen et al., 2010b). However, when virtual humans followed backchanneling opportunity rules, e.g., mimic posture shifts at certain times depending on the prosodic contours in the participant's voice (Gratch et al., 2007; Ward and Tsukahara, 2000), highly socially anxious people disclosed more intimate information to them than to humans (Kang and Gratch, 2010). This self-disclosure preference for virtual humans over human partners was not apparent for low socially anxious people (Kang and Gratch, 2010), suggesting that socially anxious individuals may benefit from mimicking virtual humans depending on how they are mimicked. Future research may consider investigating to what extent socially anxious individuals show altered person-perception in the event of being mimicked by comparing different approaches of mimicry, including ones that take backchanneling opportunity points into account (e.g., show pupil dilation mimicry when eye contact is maintained longer by the participant).

Finally, our study has several limitations that could be addressed in future research. First, the mimicry manipulation in our study was relatively subtle and effect sizes were small. The frequency of pupil dilation mimicry depended on the frequency of spontaneous pupil dilation in the participants, which was quite low in many. Stronger effects of pupil dilation mimicry on social evaluation may be observed in future studies with conditions that induce more frequent spontaneous pupil dilation, for example by using more engaging stories and/or adjusting the appearance and behavior of the virtual humans. Nevertheless, as participants saw most of the pupil dilation events, the results seem representative of situations with limited spontaneous pupil dilation. Second, we assessed the percentage of time that participants looked at the eyes of the virtual humans with a dwell time measure. Fixation-based measures may be more suitable to capture intentional aspects of eye contact. Third, we did not control for social groups which could potentially enhance the social effect of pupil dilation mimicry. In Kret et al. (2015), the social effect of pupil dilation mimicry exists for in-group partners, i.e., when the Western participants were presented with stimuli of Western eyes instead of Asian eyes. Future research may replicate this result more closely by including virtual humans whose appearances represent various social groups and registering participants' cultural affiliations. Lastly, we did not take into account agency (the extent to which the participant felt that the agent was real) or behavioral realism (the degree to which the agent behaved as expected) that the participant felt, which could influence social evaluation (Blascovich, 2002). As part of the trust game instruction, the participants were told that the virtual human was a representation of a real human, which might increase the agency of the virtual human. Since this prior information was consistent across all virtual humans, this has reduced the possible confounding factor of agency in the result. However, controlling for these two factors could be considered in future studies to better estimate the eye contact and pupil dilation mimicry effect on social evaluation.

5. Conclusion

This study builds on previous research by using stimulus materials that are more naturalistic while maintaining experimental control, therewith paving the way for future research and applications. Here we show that eye contact is positively associated with participants' social evaluation of the virtual humans, especially when the virtual humans adapt their pupil size to the participants' pupil size. Pupil dilation mimicry cannot be consciously controlled, thus, this subtle behavior could be useful in clinical studies as a measure to clarify differences in person-perception mechanisms in people with altered social functioning such as social anxiety disorder or autism spectrum disorder, which is marked by traits that cause impairments in daily life. This result also shows that equipping virtual humans with pupil dilation, especially at relevant moments such as when the participants look at the virtual human's eyes longer or when the participants' pupils are also dilated, can lead to more positive perceptions by human interaction partners.

CRediT authorship contribution statement

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

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.

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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.2025.103558.

Data availability

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

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