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Research article

# The impact of eye gaze on social interactions of females in virtual reality: The mediating role of the uncanniness of avatars and the moderating role of task type

Aleksandra Zheleva [a,*], Julie Hardeman [b], Wouter Durnez [a], Charlotte Vanroelen [a], Jonas De Bruyne [a], Dennis Osei Tutu [c], Jessica Morton [a], Jamil Joundi [c], Jelle Saldien [c], Klaas Bombeke [a]

[a] *imec-mict-UGent, Department of Communication Sciences, Ghent University, 9000, Belgium*
[b] *Department of Experimental Psychology, Faculty of Psychology and Educational Sciences, Ghent University, 9000, Belgium*
[c] *imec-mict-UGent, Department of Industrial Systems Engineering and Product Design, Ghent University, 9000, Belgium*

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## ABSTRACT

The introduction of the Metaverse and the rise of social virtual reality platforms such as VRChat has led to increased communication and collaboration in virtual reality. As interactions in social virtual reality take place through avatars, the behaviour, and in particular the eye gaze of an avatar can have an impact on the user experience. However, it is still unclear which features of the user experience are most influenced. Therefore, this study used data from 44 female participants to investigate how avatar gaze behaviour (static eyes vs. real-time tracked eyes) affects their perceived quality of communication and the amount of one-sided eye contact participants make during a communicative or collaborative task in virtual reality. In addition, the study investigated the mediating role of perceived avatar “uncanniness” (i.e., the finding that humanoid objects that imperfectly resemble real people evoke feelings of discomfort) in this relationship and the moderation effect of two multi-user scenarios (collaboration vs. communication). The results showed that uncanniness directly affected the perceived quality of communication. However, it did not significantly mediate the relationship between avatar eye gaze behaviour and the quality of communication or the amount of one-sided eye contact. Finally, there were no significant differences in user experience between the two scenarios. From this, we can conclude that the uncanniness of an avatar being interacted with in VR is not enough to hinder communication and collaboration in an immersive medium. And even if an avatar is perceived as uncanny, normative communication cues such as eye contact are still present. Notably, due to sample availability, the results of this study are based on a female-only sample. Thus, future research can benefit from exploring the outlined effects in a more gender-balanced sample.

* Corresponding author.
*E-mail addresses:* Aleksandra.Zheleva@UGent.be (A. Zheleva), Julie.Hardeman@UGent.be (J. Hardeman), wouter.durnez@gmail.com (W. Durnez), Charlotte.Vanroelen@UGent.be (C. Vanroelen), Jonas.DeBruyne@UGent.be (J. De Bruyne), dennis.oseitutu@ugent.be (D.O. Tutu), Jessica.Morton@UGent.be (J. Morton), Jamil.Joundi@UGent.be (J. Joundi), Jelle.Saldien@UGent.be (J. Saldien), Klaas.Bombeke@UGent.be (K. Bombeke).

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## 1. Introduction

Virtual environments (VEs) are steadily climbing to the top of social platforms, with the Metaverse, Viverse and VRChat at the forefront. As a result, remote communication and collaboration between multiple users is increasingly taking place [15]. However, these interactions require avatars that convincingly replicate the user's appearance and behaviour. In this study, we investigate how the mechanisms behind perceived realism can influence the quality of the user experience in VR. More specifically, we investigate how the avatar's non-verbal behaviour (e.g., eye gaze) can alter the user's objective and subjective experience in dyadic social interactions in VR and how the experienced uncanniness of such an avatar influences these relationships.

An avatar is a virtual representation of a user in an online environment (e.g. social platforms, games, VR). One of the main features of an avatar is that it can provide the user with an embodied experience [28], in which they can interact with the virtual world or other avatars in that world. Due to the immersive nature of the medium, the embodiment of an avatar in VR can also be physical (i.e. using body tracking to represent the actual movements of the user). However, a fully embodied experience is limited due to the limited availability of tracking technology – insufficient network quality leading to tracking latency, or the lack of sufficient computing power for full-body tracking in a home environment [15]. Nonetheless, research on non-verbal behaviour in face-to-face communication has provided valuable guidance on how to improve the quality of the user experience in VR without resorting to full-body tracking. One such behaviour prompt is the eye gaze of an avatar [6].

Eye gaze is an important non-verbal cue that highlights the dynamic and complex processes of communication [13]. Through gaze, we can perceive and transmit information from or to others [3,24]. Furthermore, in communication and collaboration environments, gaze has been shown to facilitate conversation [12]. Therefore, different gaze patterns of avatars in VR should be considered when trying to simulate real-life social interaction better.

Social interactions in VR include a range of behaviours and perceptions including quality of communication (QoC) [27]. Perceived QoC consists of four facets: (1) the extent to which the conversation was perceived as a genuine face-to-face conversation; (2) the extent to which the user felt engaged in the interaction; (3) the extent of copresence between users; and (4) the extent to which users positively evaluated their partner and the joint interaction [6]. Notably, previous research has not clearly shown how an avatar's gaze can affect QoC between users [27,5,6]. To address this weakness, the current study investigated the direct impact of the avatar's gaze on users' perceived quality of communication in a dyadic collaboration and communication scenario (H1a).

In addition to the subjective perception of QoC, objective behavioural measures such as eye gaze behaviour can also be used to evaluate social interactions within VR. Nowadays, most head-mounted displays (HMDs) have eye trackers built in to optimise the display of content and help users navigate through virtual environments. However, researchers have also taken advantage of eye-tracking cameras in HMDs to study users' gaze direction and patterns [16,15]. For example, Roth et al. [25] recorded participants' gaze patterns to study the impact of extending a multiuser VR museum environment. However, they focused on participants' interaction with the environment rather than with other participants. To address these gaps, the current study measured the amount of one-way (OS) eye contact in an interactive dyadic VR scenario (H1b). *OS* eye contact, person A focuses their attention on person B while person B focuses on the task or another part of the environment (or vice versa).

### *1.1. The mediation effect of perceived uncanniness*

Previous research has shown that when trying to render humanoid avatars in VR, the behavioural cues of the avatar can affect the user's perception of their perceived uncanniness [20]. More specifically, interacting with an avatar with tracked eye gaze (i.e. the avatar's gaze follows the user's real-time gaze) compared to an avatar with static eye gaze can have an impact on users' QoC and gaze behaviour [6]. This impact can be assessed through the prism of the uncanny valley effect, which occurs when an avatar is not equally realistic across different features (e.g., a graphically real avatar whose eyes move erratically) [6,18,21,26]. Indeed, Regenbrecht and Langlotz [23] have shown that virtual eye movements that approach - and yet fall short of – the level of real human interactions can produce the uncanny valley effect. However, it can be argued that if there is no such discrepancy, adding tracked glances to avatars could reduce the feeling of uncanniness during interaction in social VR [27,5]. Therefore, this research investigated the potential mediation effect of an avatar's perceived uncanniness of an avatar on the relationship between the avatar's eye gaze and QoC and users' eye gaze (H1c) (Fig. 1A and Fig. 1B).

H1: Eye-gaze behaviour of avatars is directly associated with (a) perceived quality of communication and (b) one-sided eye contact. (c) These relationships are mediated by the perception of the uncanniness of the avatar.

### *1.2. The moderation effect of task type*

Importantly, the hypothesised effects might depend on the type of interaction the user experiences in VR. In fact, the type of task participants are given is one of the most frequently cited reasons for contradictory and non-significant conclusions regarding the effects of avatar eye gaze on social interactions in VR [27,5,6]. For example, Seele et al. [27] concluded that a communication task (i.e. participants are free to talk for 2 minutes) may not elicit the same eye gaze pattern as a guessing game where there is constant back and forth between two people talking.

To address this problem, the current study extends the methodological communication paradigm to include a collaboration task where participants assemble a puzzle where each participant can only move certain pieces. This modification is based on the

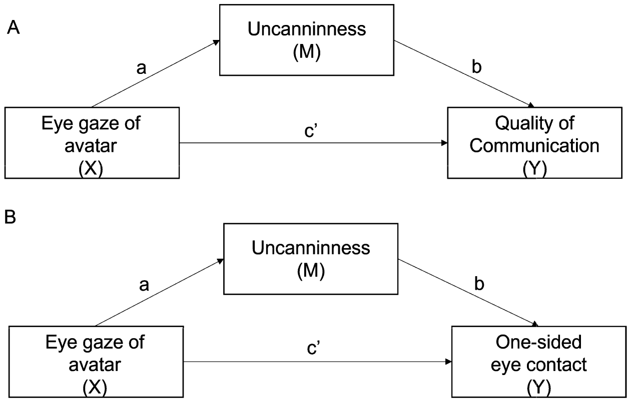


**Fig. 1.** The mediation model. *Note.* A. The mediation model for the Quality of Communication (QoC) variable; B. The mediation model for the one side (OS) eye-contact variable.; The path coefficients (a, b, c′) that estimate the strength of hypothesized causal associations are estimated by unstandardized regression coefficients. The c′ coefficient estimates the strength of the direct (also called partial) effect of the eye-gaze of the avatar on the quality of communication, that is, any effect of the eye-gaze of the avatar on the quality of communication that is not mediated by the perceived uncanniness.

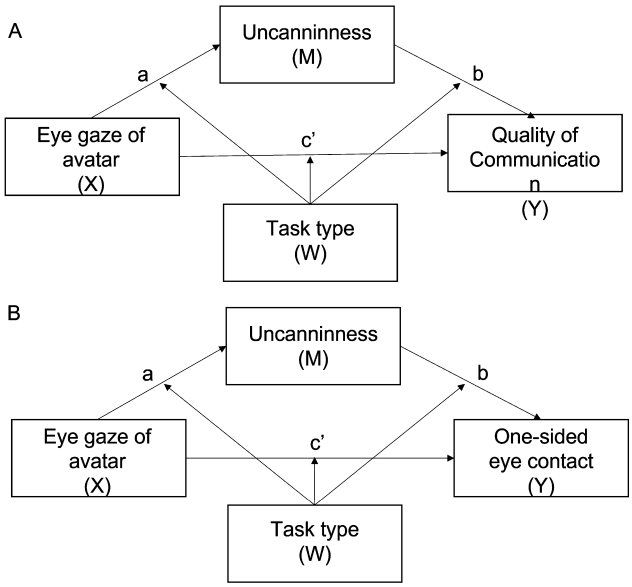


**Fig. 2.** The moderated mediation model. *Note.* A. The moderated mediation model for the quality of communication (QoC) variable; B. The moderated mediation model for the one side (OS) eye-contact variable. The path coefficients (a, b, c′) that estimate the strength of hypothesized causal associations are estimated by unstandardized regression coefficients. The c′ coefficient estimates the strength of the direct (also called partial) effect of the eye-gaze of the avatar on the quality of communication, that is, any effect of the eye-gaze of the avatar on the quality of communication that is not mediated by the perceived uncanniness.

methodological approach of Steptoe et al. [29], which used an object-oriented puzzle scenario to investigate the effects of three eye-gaze behaviours (i.e., static gaze, tracked gaze, and a gaze model) on participants' performance and subjective experience. The study showed that tracked gaze outperformed static gaze in terms of task performance and participants' subjective experience. However, these differences were not statistically significant [29]. In addition, Steptoe et al. [29] used a single-user scenario, in which they could not investigate the interaction between two users in VR. To overcome these weaknesses, the current study used multi-user collaboration and communication scenarios and examined the moderating role of task type on the direct effect of the avatar's eye gaze on participants' social interactions (H2). In addition, the study adopted a moderated mediation analysis approach, where we examined the moderating effect of task type on the hypothesised effects of the mediation model (H3, H4) (Fig. 2A and Fig. 2B).

H2. Task type moderates the relationship between the eye gaze of the avatar and uncanniness.

H3. Task type moderates the relationship between uncanniness and (a) QoC and (b) one-sided eye contact.

H4. Task type moderates the relationship between the eye gaze of the avatar and (a) QoC and (b) one-sided eye contact.

## 2. Methods

### 2.1. Participants

Forty-four female participants ($M_{age}$ = 25.68, $SD_{age}$ = 11.32) took part in the study in groups of two (i.e., dyads). Two participants reported 'less than high school' as their highest level of education. For fourteen participants, the highest level of education attained was high school, 19 participants had a bachelor's degree and nine participants had a master's degree. In addition, 24 participants indicated that this study was their first experience with VR; 17 had little experience with VR (defined as equal to or less than three times); seventeen had some experience with VR (defined as more than three times); and none of the participants indicated that they used VR regularly. Finally, 15 dyads ($N$ = 30) indicated that they had met before the study. All participants were recruited through a Facebook group dedicated to recruitment for research in the Ghent area and word of mouth.

The only inclusion criterion was that they identified as female. This criterion was used because the majority of available participants identified as female and previous research has shown significant gender differences in eye contact between same-sex dyads consisting of females as opposed to those consisting of males [30]. As the main participation pool came from a predominantly female field (i.e., psychology students) to avoid gender bias, we decided to include all female participants. Each participant signed an informed consent form and received eight euros for their participation.

### 2.2. Tasks

All dyads participated in two tasks: a communication scenario and a collaboration-based puzzle task. The communication task was a variation of the classic game 'Guess who?' as used in Seele et al. [27] (Fig. 3). At the beginning of the task, both participants were assigned the name of a character (e.g. a famous person, a historical figure or a fictional character). The name of the assigned character appeared on a card above the head of each participant's avatar. This card was not visible to the participants themselves, but it was visible to their counterpart. The aim of the communication task was to guess the assigned character by asking alternating yes-no questions. The task lasted six minutes. If a participant guessed their character within these six minutes, they were assigned a new character so that the game could continue for the scheduled time.

The collaboration task consisted of solving tangram puzzles (Fig. 3). During this task, a silhouette of the target image was displayed on the monitor in the VR environment. The pieces of the puzzle were scattered on the virtual table. Half of the pieces were coloured red and could only be moved by one of the participants, while the rest were coloured green and could only be moved by the other participant. The aim of this task was to solve the tangram puzzle by working together. If the participants managed to solve the puzzle within the planned six minutes, they were presented with a second tangram puzzle and so on until the planned duration was reached.

The continuation of both tasks was limited to six minutes so that participants could complete all tasks (2 per experimental block) and the questionnaires within one hour. The time limit of one hour was set due to the novelty of VR and the possible side effects (i.e. simulator sickness symptoms) that may occur after a prolonged VR experience. In addition, collaboration and communication in VR were facilitated by the PUN Unity package [4], which allowed participants to perform tasks in VR simultaneously and see each other's movements in real time.

### 2.3. Design

The current study used a 2×2 within-subject design in which *participant dyads* performed two *tasks* (i.e., a communication task and a collaboration task) with two *types of avatars* (i.e., one avatar with a static gaze and one with a tracked moving gaze). Participants were not informed about the manipulation of the avatar type.

To avoid a possible order effect (i.e., a better experience due to a training effect), odd-numbered dyads completed the tasks first with the avatars with static gaze (block 1) and then with the avatars with tracked moving gaze (block 2), while even-numbered dyads completed the tasks in the reverse order. While the order of avatar type was counterbalanced between participants, the order of the tasks themselves remained the same for each avatar type – the communication task always came before the collaboration task.

The flow of the experiment was created via the ExperienceTwin framework [14] (see https://www.experiencetwin.org/), which provided the ability to customise both the visual aspects (i.e. avatar type) and procedural aspect (i.e. block order) of the immersive experiment in VR.

### 2.4. Procedure

At the beginning of the experimental session, participants signed the consent form. They were then asked to complete the psychodemographic questionnaire on a laptop. Next, the experimental tasks were explained. After making sure that participants understood the tasks, they were informed about the use of the HTC VIVE Pro controllers and asked to put on a HTC VIVE Pro Eye headset (Fig. 3).

After the participants put on the HMD, an eye calibration was performed, after which they entered the virtual environment (VE). The VE was created in Unity (editor version 2019.4.29) and contained a table with two chairs in the middle (see Fig. 3). On the table was a virtual monitor that indicated when a task ended and presented the goal of the task. During the tasks, the participants' avatars sat on the other side of the virtual table. Both avatars had the body of a white woman with auburn hair and were rendered in

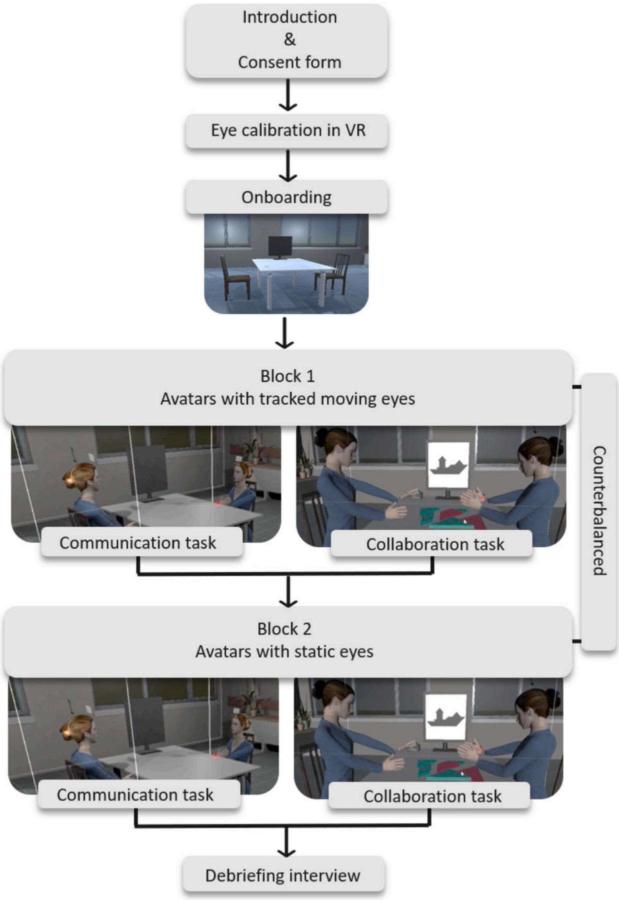


**Fig. 3.** Procedure and VR tasks.

a realistic animation graphic style similar to the most commonly used avatars in virtual social platforms. They were purchased from the Unity Asset Shop and were animation ready. We also developed and implemented eye-tracking of the avatars with moving eyes via the virtual reality toolkit [31]. To see the full VR environment and procedure you can follow the link https://bit.ly/3Dn10se.

Participants were given time (approx. 5 minutes) to get used to the VE, their avatar and their partner's avatar (i.e. onboarding). The first experimental block was then started. After completing each task, participants removed their HMD and completed a user experience questionnaire. Once both participants had completed the questionnaires, they re-entered the virtual room for the second block. After the questionnaire of the last task in the last block was completed, the participants were interviewed and received a refund.

### *2.5. Measurement tools*

#### *2.5.1. Quantitative questionnaires*

During the experiment, two questionnaires were handed out. These were programmed with Qualtrics software [22] and presented on a laptop. The questionnaires used in the study fell into two categories: (1) psycho-demographic and (2) user experience in VR. The first questionnaire captured the participants' age, gender, education level and previous experience with VR. The second questionnaire was presented after each task in VR and elicited perceptions of *QoC* [6] and *uncanniness* of the avatar they were in a dyad with. The uncanniness questionnaire examined the avatar's index of humanity, index of uncanniness and index of attractiveness [8,9]. The full set of questionnaires can be found on the project page Open Science Framework page.

#### *2.5.2. Eye gaze data*

The logging of the eye data was initiated right after the calibration procedure. Hence, the gaze direction of participants (i.e., *looking at*) was recorded as soon as participants entered the VE via the HMD integrated Tobii eye-tracking hardware [10] and the SRanipal eye-tracking software development kit [11]. The ExperienceTwin framework was used to log whether the participants were looking at the monitor, at the eyes of the other avatar or at the puzzle in the collaboration task [14]. The *looking at* data was timestamped, which helped with synchronizing the two data files of the participant dyads, thus allowing to compute the amount of one-sided eye contact.

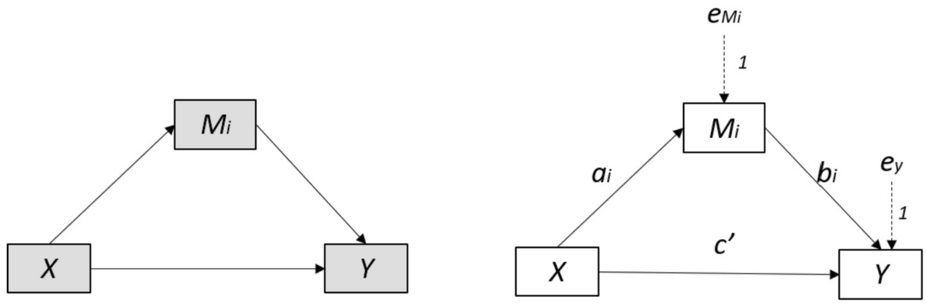


**Fig. 4.** Conceptual and Statistical Diagram of Model 4. *Note.* Indirect effect of X on Y through Mi = aibi Direct effect of X on Y = c'. Left: a conceptual diagram. Right: a statistical diagram. Source: Hayes, A. F. (2013). Introduction to mediation, moderation, and conditional process analysis: A regression-based approach. Guilford Publications.

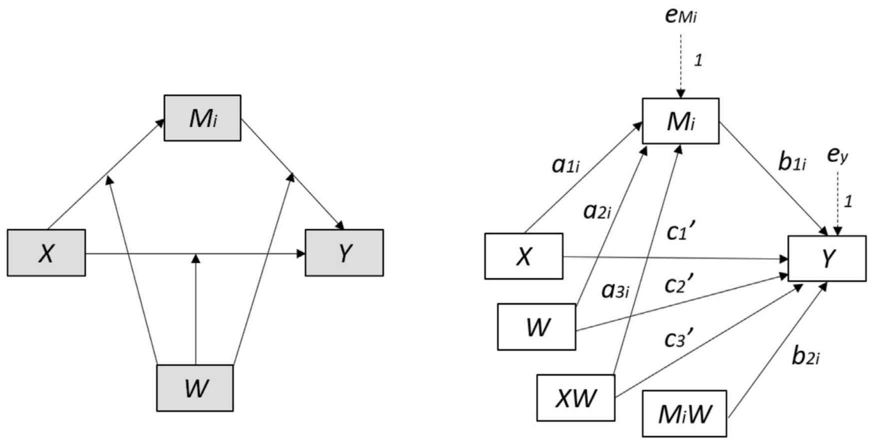


**Fig. 5.** Conceptual and Statistical Diagram of Model 59. *Note.* The conditional indirect effect of X on Y through Mi = (a1i + a3iW) (b1i + b2iW). The conditional direct effect of X on Y = c1' + c3'W. Left: a conceptual diagram. Right: a statistical diagram. Source: Hayes, A. F. (2013). Introduction to mediation, moderation, and conditional process analysis: A regression-based approach. Guilford Publications.

## 2.6. Data pre–processing

### 2.6.1. Quantitative questionnaires

A sample of 44 participants was used for the analyses of the subjective data. We computed the overall scores for *QoC* and *uncanninnes* for each participant in every task and condition (static eyes avatar vs moving tracked eyes avatar).

### 2.6.2. Eye gaze data

The raw objective data posed two challenges: (1) the eye tracking failed at times, resulting in small gaps in the data, and (2) the data was logged at a variable sample rate (± 22 ms). These two issues were addressed in the following way.

The gaps in the data consisted of missing single data points amongst a streak of *looking at X* data. Since it was physically impossible for the participant to make two subsequent saccades in this period (± 44 ms.), these sample values were interpreted as missing data and were replaced with the value of their neighbouring samples. This was done by parsing over the *looking at X* data for each participant using a sliding window of three consecutive data points. For every three consecutive data points, we checked whether the first and last data point contained an equal value (e.g., looking at eyes) but differed from the value of the middle data point (i.e., combinations such as 'eye'-'empty'-'eye'). If this was the case, the middle data point was updated to match its neighbours. The filter was applied two times to make sure there were no leftover gaps.

Next, we trimmed the data so that it included only the last 6 minutes of each of the four blocks. This step was taken to account for the difference in the duration of the initial (pre-task) adaptation of participants in VR, thus insuring we had equally long data frames. Then, the data were re-sampled to 1 ms. The interpolation method that was used for the 'looking at' data was the nearest neighbour method. The re-sampling of the data to a common, fixed sample rate allowed us to merge the data frames of both participants of each dyad, for each block. This resulted in a joint data file per dyad, which was used in the subsequent analyses. Finally, we used a set of Boolean rules to compute one-sided eye contact for both participants in each block.

**Table 1**
Hypotheses results for QoC.

| Independent variable | Dependant variable | *b* | *SE* | *t* | *p* | 95% Confidence interval | | Hypothesis |
|---|---|---|---|---|---|---|---|---|
| | | | | | | *LLCI* | *ULLCI* | |
| Eye-gaze of avatar | QoC<br>*R2* = 0.027 | 0.307 | 0.488 | 0.630 | 0.529 | -0.649 | 1.264 | H1a (PS) |
| Eye-gaze of avatar | Uncanniness<br>*R2* = 0.0005 | - 0.038 | 0.126 | -0.303 | 0.761 | -0.285 | 0.209 | |
| Uncanniness | QoC<br>*R2* = 0.027 | -0.612 | 0.293 | -2.084 | 0.038 | -1.188 | -0.036 | |
| Eye gaze of avatar X Task type | Uncanniness<br>*R2* = 0.005 | 0.016 | 0.126 | 0.127 | 0.899 | -0.232 | 0.264 | H2a (NS) |
| Uncanniness X Task type | QoC | -0.198 | e 0.298 | -0.668 | 0.504 | -0.780 | 0.383 | H3a (NS) |
| Eye-gaze of avatars X Task type | *R2* = 0.031 | -0.097 | 0.491 | -0.198 | 0.842 | -1.061 | 0.865 | H4a (NS) |

*Note. QoC* Quality of Communication, *PS* Partially supported, *NS* Not supported.

### 2.7. Statistical analysis

To investigate the study's hypotheses we performed a moderated mediation analysis [7]. The analysis was conducted via PyProcessMacro – a python implementation of Andrew F. Hayes' PROCESS Macro [1]. In particular, PROCESS Model 4 and PROCESS Model 59 were utilized as recommended by Hayes [7].

To test the significance of the mediation effect (H1), we used PROCESS Model 4 and calculated 5000 bootstrapped samples to estimate the 95% bias-corrected and accelerated confidence intervals of the indirect effect. Fig. 4 illustrates the PROCESS Model 4 conceptual and statistical diagrams. A mediation test is significant when the lower and the upper bounds of the bootstrap confidence intervals of the indirect effect between the predictor and the outcome do not include zero [7]. The process model bootstrap approach was used as opposed to the more traditional Sobel test because the bootstrap method has higher statistical power and makes more realistic assumptions about the sampling distribution of the indirect effect [17]. What is more, the method resolves the concerns associated with the Baron and Kenny [2] causal steps.

Next, to test the moderation effect (H2, H3, and H4), we ran PROCESS Model 59 with bias-corrected bootstrap confidence intervals (BC; 95% CI) based on 5000 bootstrap resamples. The conceptual and statistical diagrams of Model 59 are depicted in Fig. 5. Model 59, allows us to combine parameter estimates from a mediation analysis with parameter estimates from a moderation analysis, which in turn grants us the opportunity to quantify the conditionality of the type of task (communication vs. collaboration) on the indirect and direct effects of the mediation model [7].

## 3. Results

To address Hypothesis 1 which stated that the eye gaze of avatars is positively associated with (a) QoC and (b) OS eye contact in VR, and this relationship is mediated by the perception of the avatar's uncanniness (c), PROCESS Model 4 was conducted. Results are presented in Table 1. The eye gaze of avatars was neither a significant predictor of QoC (95% CI: [-0.649 1.264]) nor it had a significant effect on uncanniness (95% CI: [-0.285 0.209]). Sobel's test result also indicated non-significant mediation ($b$ = 0.023, $SE$ = 0.086, $Z$ = 0.271, $p$ = 0.787). Nevertheless, uncanniness was found to be a significant predictor of QoC (95% CI: [-1.188 -0.036]) (Fig. 6). In a nutshell, we cannot claim that uncanniness has a mediation effect on the relationship between the eye-gaze behaviour of avatars and the participants' QoC. However, uncanniness does have a direct negative effect on QoC.

Next, we ran another PROCESS Model 4 to investigate the effect of the eye gaze of the avatar on the amount of OS eye contact and its mediation by the perception of the uncanniness of the avatar. Results are presented in Table 2. The eye gaze of avatars was neither a significant predictor of OS eye contact (95% CI: [-1.032 1.538]) nor it had a significant effect on uncanniness (95% CI: [-0.288 0.204]). Uncanniness was also found to be a non-significant predictor of OS eye contact (95% CI: [0.942 0.609]). Furthermore, the Sobel test result confirmed the non-significant mediation ($b$ = 0.007, $SE$ = 0.071, $Z$ = 0.098, $p$ = 0.928). All in all, we cannot claim that uncanniness has a mediation effect on the relationship between the eye-gaze behaviour of avatars and the amount of one-sided eye contact participants engaged in during their experience.

To investigate Hypotheses 2 (task type moderates the relationship between eye gaze of avatars and uncanniness), 3 (task type moderates the relationship between eye gaze of avatars and QoC), and 4 (task type moderates the relationship between uncanniness and QoC) PROCESS Model 59 was conducted. The results indicated that task type was not a significant moderator of the relationship between the eye-gaze behaviour of avatars and uncanniness (95% CI: [0.232 0.264]). Furthermore, the "uncanniness x task type" (95% CI: [0.780 0.383]) and "eye-gaze behaviour of avatars x task type" (95% CI: [-1.061 0.865]) interaction terms effects were also not statistically significant (see Fig. 6).

Finally, we ran another PROCESS Model 59 to investigate Hypotheses 2 (task type moderates the relationship between eye gaze of avatars and the amount of OS eye contact), 3 (task type moderates the relationship between uncanniness and the amount of OS eye contact), and 4 (task type moderates the relationship between eye gaze of avatars and the amount of OS eye contact). As seen in Fig. 7, there was no effect of task type moderating the relationship between the eye-gaze behaviour of avatars and uncanniness (95% CI: [0.235 0.258]). Moreover, the "uncanniness x task type" (95% CI: [-0.630 0.659]) and "eye–gaze behaviour of avatars x task type" (95% CI: [1.406 0.724]) interaction terms effects were also not statistically significant.

**Table 2**
Hypotheses results for one-sided eye contact.

| Independent variable | Dependant variable | *b* | *SE* | *t* | *p* | 95% Confidence interval | | Hypothesis |
|---|---|---|---|---|---|---|---|---|
| | | | | | | *LLCI* | *ULLCI* | |
| Eye-gaze of avatar | OS eye contact $R2 = 0.002$ | 0.253 | 0.656 | 0.385 | 0.700 | -1.032 | 1.538 | H1b (NS) |
| Eye-gaze of avatar | Uncanniness $R2 = 0.0006$ | - 0.042 | 0.125 | -0.334 | 0.738 | -0.288 | 0.204 | |
| Uncanniness | OS eye contact $R2 = 0.002$ | -0.166 | 0.395 | -0.421 | 0.674 | -0.942 | 0.609 | |
| Eye gaze of avatar X Task type | Uncanniness $R2 = 0.005$ | 0.011 | 0.126 | 0.092 | 0.926 | -0.235 | 0.258 | H2b (NS) |
| Uncanniness X Task type | OS eye contact | 0.014 | 0.329 | 0.045 | 0.964 | -0.630 | 0.659 | H3b (NS) |
| Eye-gaze of avatars X Task type | $R2 = 0.326$ | -0.341 | 0.543 | -0.627 | 0.531 | -1.406 | 0.724 | H4b (NS) |

*Note. OS* One-sided, *NS* Not supported.

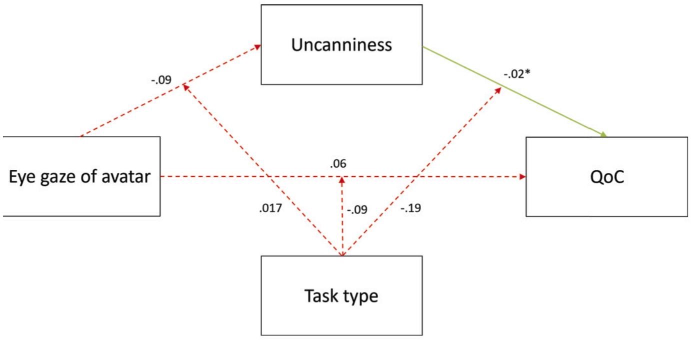


**Fig. 6.** The effect of uncanniness on QoC moderated by task type. *Note.* Dashed red lines represent insignificant paths.; * $p < .05$.

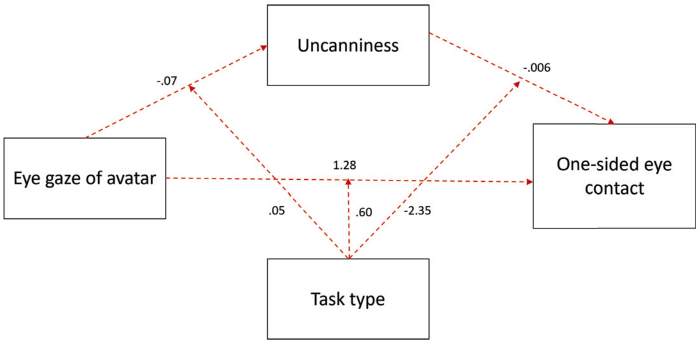


**Fig. 7.** The effect of uncanniness on one-sided eye contact moderated by task type. *Note.* Dashed red lines represent insignificant paths.

## 4. Discussion and conclusion

This study explored the mediation effect of the uncanniness of avatars with either a static eye gaze or tracked moving eye gaze on the participants' perceived quality of communication. Furthermore, objective markers of social interaction such as one-sided eye contact were explored. Finally, we investigated the potential moderator effect of the type of task that the users had to engage in (i.e., communication vs. collaboration). Notably, the currently discussed outcomes are based on a fully female sample. Thus, the listed conclusions and repercussions of the research should be viewed through this prism. First of all, it should be noted that the direct relationship between the avatar's eye-gaze behaviour and the social interaction markers was non-significant, thus illustrating the complexity of the relationship (i.e., simply introducing eye-gaze behaviours in avatars might not be enough to alter the users' experience). Furthermore, the mediation analysis showed that uncanniness did not mediate the relationship between the avatar gaze behaviour and the quality of communication or the amount of one-sided eye gaze. Interestingly, however, uncanniness had a significant direct negative effect on the perceived quality of communication. Finally, the type of task was not a significant moderator in the mediation model. Notably, we did not find the expected effect of tracked moving eye gaze on the participants' subjective and objective experience. This could be due to the following limitations and considerations.

First, the tracking of the controllers via two light stations proved to be insufficient in supporting the four HTC Vive controllers that were used during the collaboration task. This sometimes led to unnatural movements of the avatar's arms or body that might have incidentally contributed to the uncanniness of the avatar. Furthermore, the tracking limitations also resulted in unnatural eye movements of the avatars thus compromising their visual fidelity. Although these occurrences were rather infrequent they might have affected the participants' overall feeling of immersion and their impression of the avatar's realism [6,18,21,26].

Second, it is worth mentioning that eliciting realistic reactions to social stimuli within virtual environments seems to be more complex, and a deeper understanding of the participants' cognitive process is required to achieve them [16]. Primarily, one should keep in mind that the increased realism of the avatars' eye movement might not be enough to elicit feelings of immersion. On the contrary, the VR user interprets all aspects of the non-verbal behaviour of avatars (e.g., body movements, gestures, full facial expressions). Indeed, previous studies have already hinted that the avatars' overall behavioural response might impact the reported levels of perceived realism and change the users' perception of the avatars' uncanniness [19]. However, since we conducted the study during a period of anti-covid health measures all participants were wearing face masks. This prohibited us from further improving the avatars' realism via face tracking, as the participants' masks would cover their faces. Indeed, during the debriefing interviews, some participants suggested that the avatar would look more real if the mouth would move along when the other person spoke. Another participant also indicated that they found it hard to tell when their partner was about to speak because the mouth did not move. In addition, the responsiveness of the avatar and interactivity with the environment can also affect the users' perception of behavioural realism and immersion in the VE [16]. Thus, our future research will aim to incorporate facial and (or) body tracking in the effort to investigate users' perceptions of the avatar's realism and their immersion in the VE.

Third, it is vital to consider the current results in light of the fact that the current study relied on a fully female sample. This was a conscious decision based on the availability of the participation pool (which was predominantly female). If we were to remove the recruitment criteria we would not have ended up with an even distribution of gender within and between dyads which could have affected the outcome variables. For example, Swaab and Swaab [30] have shown that direct eye contact is important in building a shared understanding among two females, which aids better cooperation and collaboration. On the other hand, direct eye contact can be an obstacle for two males, which can in turn impair their collaboration. Therefore, by incorporating a females-only sample we controlled for the confounding effects gender might have on the collaboration in VR. However, this decision also constrained the validity of our results as their applicability to a wider sample is seriously limited. However, this was a valuable first step towards our future investigation of patterns of communication and collaboration in social VR settings. Indeed, we are currently designing a study that carries out the current research objectives with an improved task design and different recruitment strategy - we will expand our recruitment to other university faculties (e.g., Faculty of Engineering), to gain a more representative sample both in terms of size and gender distribution.

All in all, in spite of the female-only sample this study is a valuable step towards understanding the added value of eye-tracking in experimental design in VR. Moreover, this paper illustrates the complex nature of the user experience in VR and how simply improving the eye gaze patterns of avatars might not be enough to improve the user's overall social interactions in VR. Furthermore, this study suggests that the perceived uncanniness of an avatar with which one interacts in VR might not be enough to obstruct communication and collaboration in the immersive medium. Therefore, future research is encouraged to investigate user experience in VR with increased consideration of the intricate mental states the user is going through during their VR experience. Moreover, studies should investigate the multitude of content and system-related factors (e.g., the fidelity of graphics and tracking accuracy) that might cumulatively form the user experience.

## Ethics statement

This study has been approved by the Ghent University Faculty of Political and Social Sciences Ethical Committee (2021-51).

## CRediT authorship contribution statement

**Jonas De Bruyne**; **Klaas Bombeke**: Conceived and designed the experiment; Wrote the paper. **Wouter Durnez**, **Jelle Saldien**, **Jessica Morton**, **Jamil Joundi**: Conceived and designed the experiment. **Julie Hardeman**: Conceived and designed the experiment; Performed the experiments. **Aleksandra Zheleva**: Conceived and designed the experiment; Analyzed and interpreted the data; Wrote the paper. **Charlotte Vanroelen**: Contributed reagents, materials, analysis tools or data. **Dennis Osei Tutu**: Contributed reagents, materials, analysis tools or data; Wrote the paper.

## Declaration of competing interest

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

## Data availability

Data associated with this study has been deposited in the Open Science Framework at https://bit.ly/3aiAQe9.

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## Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e20165.

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