The impact of model eyesight and social reward on automatic imitation in virtual reality

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Abstract

Motivational theories of imitation state that we imitate because this led to positive social consequences in the past. Because movement imitation typically only leads to these consequences when perceived by the imitated person, it should increase when the interaction partner sees the imitator. Current evidence for this hypothesis is mixed, potentially due to the low ecological validity in previous studies. We conducted two experiments ($N_{\text{exp1}} = 94$, $N_{\text{exp2}} = 110$) in which we resolved this limitation by placing participants in a virtual environment with a seeing and a blindfolded virtual agent, where they reacted to auditory cues with a head movement to the left or right, while the agent(s) also made a left or right head movement. We tested the effect of model eyesight (Experiments 1 and 2) and social reward on imitation (Experiment 2). Data were collected in 2023 and 2024. As expected, participants tended to imitate the agents. However, we found only limited evidence for the effect of model eyesight on automatic imitation in Experiment 1 and no evidence for the effect of model eyesight or social reward in Experiment 2. These findings challenge claims made by motivational theories.

Keywords: Automatic imitation, social reward, model eyesight, motivational theories, virtual reality

Public Significance Statement

Motivational theories argue that humans imitate more in situations where imitation is more likely to have positive social consequences. Based on this, it has been hypothesized that movement imitation should be stronger when the model can see the imitator because only then imitation can lead to a positive reaction. However, evidence for this effect has been mixed, potentially due to the low ecological validity of previous tasks. In two experiments, we use virtual-reality tasks to address this issue and thereby maximize the putative effect of model eyesight. In Experiment 2, we also tested the effect of the model's emotional reaction to imitation. We found only limited evidence for the effect of the other person's sight in Experiment 1, whereas no such effect was found in Experiment 2. Furthermore, imitation was not influenced by whether the other person (dis)liked being imitated. These findings raise fundamental questions about whether automatic imitation can be socially influenced.

Humans have an automatic tendency to copy the behavior of others, including their mannerisms (Chartrand & Bargh, 1999; Tschacher et al., 2014), gestures (Cracco, Genschow, et al., 2018), facial expressions (Dimberg, 1982; Dimberg et al., 2000), and eye gaze (Cracco et al., 2022; Driver et al., 1999; Milgram et al., 1969). According to the Associative Sequence Learning (ASL) model, these imitative tendencies emerge from a link between perceptual and motor representations of actions in the brain, formed through repeated sensorimotor experiences over the course of development. As a result, the perceptual representation of an action automatically activates its corresponding motor representation, leading to the tendency to imitate observed movements (Catmur et al., 2009).

These imitative tendencies are, in turn, thought to support successful social interaction by fostering affiliation between the imitator (i.e., the person who imitates) and the imitated person (Hess & Fischer, 2013, 2022; Lakin et al., 2003). For instance, imitation has been found to increase empathy (De Coster et al., 2013; Stel & Vonk, 2009) and trust (Maddux et al., 2008; Over et al., 2013; Verberne et al., 2013) toward the imitator, as well as liking between the interaction partners (Chartrand & Bargh, 1999; Salazar Kämpf et al., 2018; for a review, see Chartrand & Lakin, 2013). Based on these findings, motivational theories argue that imitation can be seen as a strategy to obtain social reward, such as affiliation with others (Stel et al., 2016; Wang & Hamilton, 2012). In line with this idea, research has shown that imitation increases when individuals are more motivated to affiliate with other people, for example, after being socially excluded (Lakin et al., 2008) or after being primed with prosocial cues (Lakin & Chartrand, 2003; Leighton et al., 2010).

However, imitation will not always lead to social reward. For example, imitating the movements of someone who cannot see you is unlikely to cause them to like you more because they do not see your imitative behavior. Motivational theories incorporate these contextual constraints by arguing that individuals imitate more if imitation can be expected to produce social reward in that particular context (Stel et al., 2016). This implies that imitation can be seen as a form of operant behavior, with social reward as the reinforcer and contextual cues like whether the other person sees the imitator as discriminative stimuli determining if imitation is likely to lead to such reward (Wang & Hamilton, 2012). Previous research typically investigated this prediction by manipulating the gaze direction of a model. These studies found that a direct gaze from a model (vs. an averted gaze) not only leads to increased motor activation in the brain during observation of hand movements (Prinsen et al., 2017, 2018; Prinsen & Alaerts, 2019) but also more imitation of the model's hand movements (Wang et al., 2011; Wang & Hamilton, 2014). However, recent research, including a well-powered study by Carr et al. (2021), could not replicate this effect on imitation (Carr et al., 2021; Farmer et al., 2021). Hence, the evidence for the effect of gaze direction on imitative tendencies is not yet conclusive.

There are two limitations in previous research that could have caused this inconsistency in the literature. The first limitation is the low ecological validity of the imitation tasks typically used to study the influence of social factors on imitation. Most research on this topic uses the imitation-inhibition paradigm to measure automatic imitation (Carr et al., 2021; Farmer et al., 2021; Wang et al., 2011; Wang & Hamilton, 2014). In this task, participants respond to symbolic cues with certain hand movements, while a hand in the background performs a congruent movement (identical to the correct response) or an incongruent movement (different from the correct response) (Brass et al., 2000; Cracco, Bardi, et al., 2018). Participants tend to respond more slowly and with lower accuracy when the hand performs an incongruent compared to a congruent movement (Brass et al., 2000). Although this congruency effect has been replicated in various studies (Cracco, Bardi, et al., 2018) and proven to be a reliable (Genschow et al., 2017) and valid (Cracco & Brass, 2019) index of covert imitative tendencies, it is very different from how imitation typically occurs in real life. Whereas the imitation-inhibition task measures covert imitation of meaningless hand movements on a computer screen (Brass et al., 2000; Cracco, Bardi, et al., 2018), everyday situations typically involve overt imitation of meaningful social behavior. Therefore, this task might be suboptimal to test the predictions by motivational theories, which focus on these real-life imitative tendencies (Stel et al., 2016; Wang & de Hamilton, 2012). Despite attempts to make the task more social, such as presenting a picture of a person together with the hand (e.g., Forbes et al., 2017; Wang et al., 2011), the imitation-inhibition imitation task remains rather artificial. A possible solution to this problem is to use real-life interactions to study imitation (e.g., Chartrand & Bargh, 1999). However, whereas these paradigms have higher ecological validity, they have lower experimental control and reliability (Genschow et al., 2017).

Besides the limited ecological validity, a second limitation in previous work is the absence of direct social comparison. In daily life, we often observe multiple individuals acting simultaneously, whereas only a single hand is typically shown in each trial during imitation tasks. This distinction is important because, according to social judgment theories, humans typically evaluate someone by comparing them to a salient reference within a specific context (Mussweiler, 2003). Hence, it is possible that certain characteristics of a model influence imitation only when this model is compared to another model that serves as a reference. By presenting only one model per trial and comparing the effect of whether this model looks at the participant across trials, the social comparison between both models has been merely implicit, potentially attenuating the effect of the model’s gaze direction on imitative tendencies. In contrast, when participants observe two models simultaneously, the fact that only one of both models looks at them becomes an important distinguishing factor between the two, potentially driving differences in imitative behavior.

To resolve both limitations in previous work, the current study builds on a recent study by Cracco et al. (2022) to investigate the effect of whether the other person sees the imitator on imitation. In their study, Cracco et al. (2022) bridged the gap between the artificial imitation-inhibition task and more naturalistic paradigms by using virtual reality (VR). More precisely, they created an immersive VR imitation task in which they measured imitation of socially relevant behavior, namely gaze following. Participants were placed in a virtual city with ten life-sized virtual agents. Once in a while, a sound was played, which cued participants to look up to the left or right target window, in which a fire was burning. At the same time, a variable number of virtual agents also looked up to the left or right target location. Imitation was assessed by measuring the influence of the virtual agents' movements on the participant's behavior. Automatic imitation was measured via the congruency effect in forced-choice trials, identical to how it is typically measured in an imitation-inhibition task. However, because in daily life, people can typically choose their responses, and thus also choose (not) to imitate, Cracco et al. (2022) also added another measure of imitation via so-called free-choice trials. In these trials, there was no correct response and participants could choose (not) to follow the virtual agents' movements, thereby representing real-life imitative tendencies more closely.

Cracco et al. (2022) effectively measured participants' imitative tendencies in both forced- and free-choice conditions. Moreover, they replicated findings from previous research using the typical imitation-inhibition task, by showing that automatic imitation increased with the number of observed movements (Cracco et al., 2015; Cracco & Brass, 2018). Altogether, by using VR, the researchers could increase the ecological validity of the typical imitation-inhibition task while also retaining experimental control (Parsons, 2015), thereby resolving the first limitation in previous research.

To resolve the second limitation, we adapted this VR task to align with theories of social judgment. First, only two agents were present during the task: one blindfolded agent and one agent who looked directly at the participant. By presenting both agents together in each trial, we emphasized the agent’s eyesight as a distinguishing feature between them. Second, we included two different trial types to measure the effect of model eyesight both across and within trials. In the majority of the trials, one of both agents (i.e., the seeing or the blindfolded agent) looked in a certain direction, similar to the trials in Cracco et al. (2022). Based on the predictions by motivational theories, we expected to find more imitation of the seeing agent compared to the blindfolded agent across trials. More precisely, we expected participants to show a stronger congruency effect for this agent (forced-choice trials) and to follow this agent more frequently (free-choice trials) compared to the blindfolded agent. However, there were also trials in which both agents looked in opposite directions, which allowed us to compare the effect of model eyesight within trials. When both agents move differently, the differences between both agents become essential, as participants are forced to imitate either the seeing or the blindfolded agent and counter-imitate the other (for a similar design, see De Souter et al., 2021). Therefore, these trials were added to maximize the effectiveness of the model eyesight manipulation. Whereas the effect of the models’ movements is usually canceled out when they move differently, causing the congruency effect to disappear (Cracco et al., 2015), we expected to find stronger imitative tendencies for the seeing agent, reflected in a congruency effect in the direction of this agent and more frequent follow choices for this agent.

Experiment 1

Method

Transparency and Openness

All data and analysis code for the analyses for Experiment 1 (https://osf.io/m2gqy/?view_only=3dfeeb8881ba4392bc439039eb0f1e3f) and Experiment 2 (https://osf.io/yzjp3/?view_only=e11270f9ed724f4f9c9698e82f140309) are available on the Open Science Framework (OSF). Data were processed and analyzed using R (version 4.3.1; R Core Team, 2023). We report all measures and manipulations, and how we determined the sample size and participant and data exclusions. The experiments' designs, hypotheses, and confirmatory analyses were preregistered on the OSF; see https://osf.io/jvgbq/?view_only=f1dad060f66347a0a888100e5f8ecf27 for Experiment 1 and https://osf.io/9e28j/?view_only=0bd084c5273043e28c175f6d14350fb7 for Experiment 2. For both experiments, there were no departures from the preregistered plan for the confirmatory analyses, and analyses that were not preregistered are identified as exploratory. Both experiments were approved by the ethical committee of the Faculty of Psychology and Educational Sciences with reference number 2023-004.

Participants

Participants were recruited through the research participation system of Ghent University (Sona Systems) and social media posts. Data for this study were collected in 2023. Ninety-eight participants took part in this study in return for course credit or €10. Participants who took part in return for course credit (*N* = 77) were first-year psychology students at Ghent University. All participants had normal or corrected-to-normal vision, were Dutch-speaking, were naïve to the purpose of the experiment, and signed an informed consent before the start of the procedure. They were further informed that a side effect of VR is that some people get dizzy or nauseous (Pan & Hamilton, 2018). Two participants could not complete the VR task because they experienced dizziness during the experiment. One of these participants did not complete the first experimental block and was therefore excluded. For the second participant, we used their data for two of the four experimental blocks. After further exclusions (see the Analysis section for details), the final sample consisted of 94 participants for the analysis of the forced-choice trials (58 female, 33 male, 2 non-binary, 1 "rather not say", $M_{\text{age}} = 20.36$, $SD_{\text{age}} = 3.08$) and 91 participants for the analysis of the free-choice trials (56 female, 32 male, 2 non-binary, 1 "rather not say", $M_{\text{age}} = 20.41$, $SD_{\text{age}} = 3.11$).

The minimum sample size was determined via a power analysis with simulated data using the mixedpower package for mixed-effects models (Kumle et al., 2021). The power analysis was based on the expected effects in trials in which only one agent moved, because these trials are similar to trials in the study by Cracco et al. (2022). We aimed to detect the same main effects as Cracco et al. (2022) for the preregistered primary outcome measures (i.e., reaction times (RTs) and error rates (ERs) on forced-choice trials and follow decisions on free-choice trials) but multiplied these effects by 75% to obtain a conservative estimate. This corresponded to an estimated main effect of 27 ms for RTs, 4% for ERs, and 7% for the follow decisions. We then divided the obtained effect sizes by two to estimate the interactions of interest (Baranger et al., 2023). The power analysis indicated that a sample of 90 participants would allow us to detect these effects with ≥ 82% power and a significance threshold of 0.05.

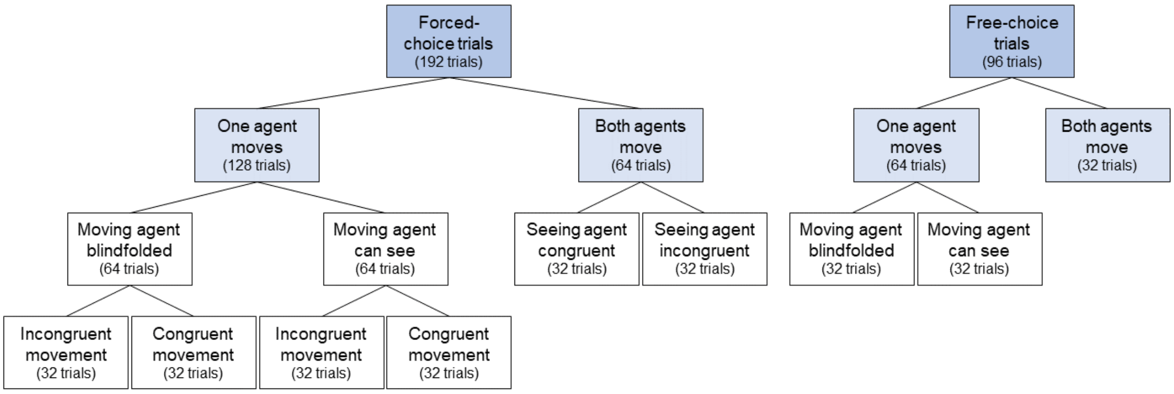
Design

Forced-Choice Trials. For trials in which one agent moved, the within-subject factors were the agent's eyesight (blindfolded, can see) and movement congruency (congruent, incongruent). For trials in which the two agents looked in opposite directions, the within-subject factor was the movement congruency of the seeing agent (congruent, incongruent). Because both agents made different movements in these trials, the congruency effect for one agent was always the opposite of the congruency effect for the other agent. Therefore, a positive congruency effect for the seeing agent implies that this agent caused a stronger congruency effect than the blindfolded agent. The primary outcome measures for these trials were RTs and ERs. We included the partial errors and movement times (MTs) as secondary outcome measures.

Free-Choice Trials. For trials in which one agent moved, the within-subject factor was the agent's eyesight (blindfolded, can see). The primary measure of interest was the participant's choice (not) to follow the moving agent. For trials in which the two agents looked in opposite directions, we simply measured whether participants followed the seeing agent instead of the blindfolded agent. RTs, MTs, and partial choices were analyzed as secondary outcome measures. Figure 1 represents a visual overview of all the different trial types and conditions.

Figure 1

Overview of the Different Trial Types in the Design of Experiment 1



Note. The colored boxes represent trial types. The white boxes are the different conditions within the trials. Note that there were no conditions in free-choice trials in which both agents moved.

Task and Procedure

The study took place in the faculty of Psychology and Educational Sciences at Ghent University (Belgium). Participants first received written instructions, which explained that they would perform a task together with two virtual people. These instructions explicitly mentioned that one virtual person would be blindfolded during the task and were accompanied by a picture of the agents in which one of them wore the blindfold. This was done to ensure participants recognized the blindfold. After the instructions, participants put on the head-mounted display (HMD). We used an HTC Vive Pro HMD with built-in headphones, a visual field of 110° with a resolution of 1440 x 1600 pixels per eye, and a refresh rate of 90 Hz. Next, participants completed nine practice trials of the VR experiment with auditory accuracy feedback. Participants heard a “ping” sound if they provided the correct response and a “buzz” sound if they made an error. All responses were considered correct in free-choice trials. If necessary, participants could repeat the practice phase once more before proceeding to the test phase. The test phase contained 288 trials without accuracy feedback, divided into four blocks with 72 trials each. All conditions were randomized within each block. The agent who wore the blindfold alternated across blocks, which means that each agent wore the blindfold in two of the four blocks. Which agent wore the blindfold in the first block was counterbalanced across participants.

The VR environment was constructed in Unity Engine (version 2019.4.29f), based on the environment used in Cracco et al. (2022). Participants stood on a street, surrounded by apartment buildings. Two virtual agents, a male and a female agent, stood in front of the participant. The virtual agents and their animations were created using the Character Creator and iClone software from Reallusion (2022). The position of these agents (i.e., left or right) was counterbalanced across participants. Both agents had a subtle smile during the task because an entirely neutral expression could come across as not socially engaging (Wang &

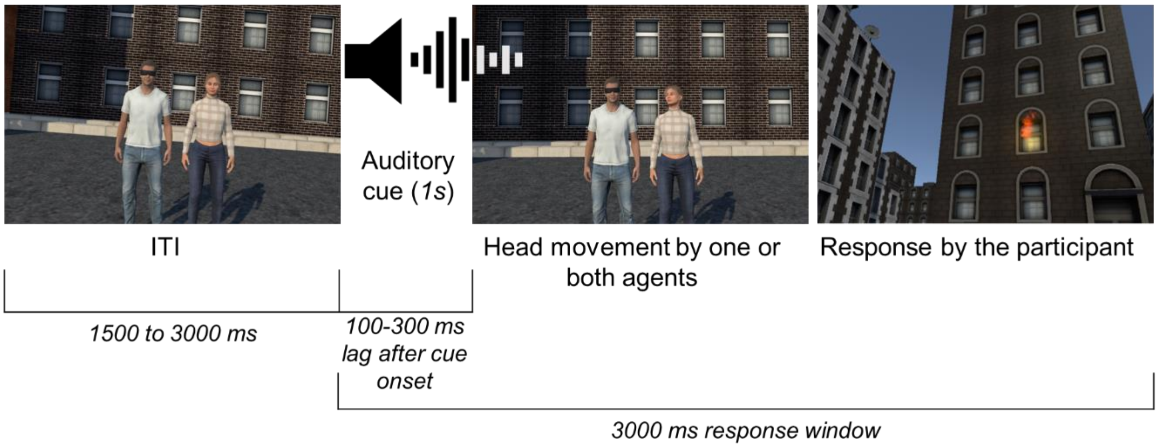
Hamilton, 2014). The buildings left and right of the participant contained a window in which a fire was burning. These windows were used as target locations in the imitation task.

Figure 2 provides an example trial of the VR task. Each trial started with a variable period of 1500 to 3000 ms (randomized in steps of 500 ms), after which a sound was played to cue the correct response. This sound was non-directional, which means that it was presented simultaneously to both ears. There were three distinct sounds used, each with a total duration of one second: an explosion, a collapsing structure, and breaking glass. One sound – for example, the explosion – indicated that participants had to make a head movement toward the left window (forced-choice trial). The second sound – the collapsing structure – indicated that they had to look at the right window (forced-choice trial). The third sound – breaking glass – indicated that participants were free to choose in which direction to look (free-choice trial). However, they were asked to balance the number of times they looked at the left versus right window across trials without using an explicit strategy (e.g., switching between the windows on each free-choice trial) (Arrington & Logan, 2004; Vandierendonck et al., 2010). The sound-response mapping was counterbalanced across participants.

One hundred to 300 ms after the start of the sound (randomized in steps of 100 ms), one virtual agent (192 trials: 128 forced-choice, 64 free-choice) or both virtual agents (96 trials: 64 forced-choice, 32 free-choice) looked at one of the two target locations. If both virtual agents made a head movement, they always looked in opposite directions. In forced-choice trials, the agent(s) could look at the correct window (congruent trial) or the incorrect window (incongruent trial). In free-choice trials, there was no (in)correct response. Participants could respond from the start of the auditory cue until the response deadline of 3000 ms. When the participant’s gaze reached one of the target windows, the fire was extinguished to indicate that their response was registered. The next trial immediately started when the participant looked back in the direction of the virtual agents.

Figure 2

Example Trial in the Virtual Reality Task of Experiment 1 From Participant Viewpoint



Note. The duration of the auditory cue was one second, which means that the sound was still playing during the head movement by the agent(s).

After the VR task, participants were asked to provide their demographic information and complete several questionnaires on a laptop. They first indicated their age and gender. To indicate their gender, participants could choose one of the following options: “male”, “female”, “non-binary”, “not listed”, or “prefer not to say”. If they indicated that their gender was “not listed”, they could fill in an alternative. Participants then completed three questionnaires, the Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001), the Social Reward Questionnaire (Foulkes et al., 2014), and the Need To Belong Scale (NTBS; Leary et al., 2013), in a randomized order. These questionnaires were used for an exploratory analysis, for which the materials, analysis, results, and discussion can be found in the Supplementary Materials (S1). Students who participated in return for course credit were debriefed via e-mail after data collection was finished. Participants could also share their e-mail address if they wished to obtain a summary of the study results.

Analysis

Calculation of the Outcome Measures. The x, y, and z coordinates of the HMD were continuously tracked throughout the experiment to measure the precise onset and direction of the participant's head movement together with the moment they reached the target location. We followed the procedure from Cracco et al. (2022) to calculate the participants' RTs, ERs, MTs, partial errors/choices, and the participant's decision (not) to follow the agent(s).

RT was defined as the onset of the upward movement toward one of the targets. To calculate this measure, we determined the first derivative of the HMD position on the y-axis (up/down), which represents the velocity of the upward movement at each time point. We then searched for the last time point at which this first derivative was ≤ 0 before reaching its maximum value, indicating the onset of the upward head movement. MT was defined as the duration of the head movement. This measure was calculated by subtracting RT (i.e., the onset) from the first timepoint at which the y-axis' (up/down) first derivative was ≤ 0 again after reaching its maximum, indicating the end of the head movement.

Partial errors (forced-choice trials) and partial choices (free-choice trials) were trials in which the participant first moved their head in the direction of one target location but then changed direction and hit the other target instead. Partial errors/choices were calculated by taking the first derivative of the HMD position on the z-axis (left/right) and recoding the obtained values such that values reflected a movement in the direction of the participant's final target. We then searched for a substantial deviation in the opposite direction. More specifically, if there was a five-point local minimum of <-0.05 preceding the maximum first derivative value, a partial error/choice was registered. The final target was saved as the chosen response.

Participant and Trial Exclusion. Participant and trial exclusions were preregistered on the OSF (https://osf.io/jvgbq/?view_only=f1dad060f66347a0a888100e5f8ecf27).

Participants were excluded from all analyses if their ER on forced-choice trials was ≥ 40% (none). Three participants were excluded from the forced-choice analysis because their ER exceeded the average ER in the sample with ≥ 2.5 *SD* or because their mean RT on forced-choice trials was ≥ 2.5 *SD* above or below the mean RT in the sample. Six participants were excluded from the free-choice analysis because they chose the same target on ≥ 75% of the trials or because their mean RT on free-choice trials was ≥ 2.5 *SD* above or below the mean RT in the sample. Ninety-four participants (58 female, 33 male, 2 non-binary, 1 "rather not say", $M_{\text{age}} = 20.36$, $SD_{\text{age}} = 3.08$) were included in the forced-choice analysis and 91 participants (56 female, 32 male, 2 non-binary, 1 "rather not say", $M_{\text{age}} = 20.41$, $SD_{\text{age}} = 3.11$) were included in the free-choice analysis.

Trials were excluded from all analyses if the RT was ≤ 200 ms (0.45%), if the RT was ≥ 4000 ms (0.00%), or if the MT was ≥ 2000 ms (0.01%). In addition, trials were excluded from the forced-choice RT/MT analysis if the response was incorrect (1.71%) or if a partial error was made (8.59%). In the RT/MT analysis, trials were also excluded if the RT was ≥ 2.5 *SD* above or below the participant's mean RT (1.97%) or if the MT was ≥ 2.5 *SD* above or below the participant's mean MT (1.92%). The same criteria were used in the partial error analysis, except that partial errors were included, and in the forced-choice ER analysis, except that the errors were included. Trials were excluded in the error (3.10%) and partial error (4.08%) analyses if the RT and/or MT was ≥ 2.5 *SD* above or below the participant's mean RT/MT.

Apart from the trials that were excluded from all analyses, trials were also excluded from the free-choice RT/MT/participant's decision analysis if a partial choice was made (7.63%), if the RT was ≥ 2.5 *SD* above or below the participant's mean RT (1.76%) or if the MT was ≥ 2.5 *SD* above or below the participant's mean MT (1.71%) on free-choice trials without partial choices. The same criteria were used for trial exclusion in the partial choice analysis, except that partial choices were included. In this analysis, 3.54% of the trials were excluded because the RT and/or MT was ≥ 2.5 *SD* above or below the participant's mean RT/MT on free-choice trials.

Preregistered Data Analysis. RTs and MTs were analyzed with linear mixed-effects models (Bates et al., 2015) and p-values were calculated using the Satterthwaite correction for linear mixed-effects models, implemented via the lmerTest package (version 3.1.3; Kuznetsova et al., 2017). As a measure of effect size, we report the beta estimates and their 95% confidence interval. ERs, partial errors, partial choices, and the participant's decision were analyzed with generalized mixed-effects models, using the binomial logit link function (Baayen et al., 2008; Bates et al., 2015). P-values were calculated using Wald Chi-Square tests for generalized mixed-effects models. We report the unsigned z-values and add the odds ratios and their 95% confidence interval as a measure of effect size. Type three sum of squares and contrast coding were used in all analyses. The random-effects structure of the models was determined through the procedure suggested by Scandola and Tidoni (2024) to balance type I and type II errors. This procedure fits complex random intercepts rather than random slopes, which allows us to fit more complex models without convergency or singularity issues (i.e., the statistical procedure fails to fit an optimal model with the given fixed and random effect structure).

Models in Forced-Choice Trials. RTs and ERs were the primary measures of interest in forced-choice trials. MTs and partial errors were analyzed as secondary outcome measures. For trials in which only one agent moved, the moving agent's eyesight (blindfolded, can see) and movement congruency (congruent, incongruent) were included as fixed within-subject factors. For trials in which the two agents looked in opposite directions, only the seeing agent's congruency was included as a fixed within-subject factor. Because both agents made opposite movements, a congruent movement by the seeing agent implied an incongruent movement by the blindfolded agent, and vice versa.

Models in Free-Choice Trials. For trials in which only one agent moved, the primary measure of interest for free-choice trials was the participant's decision (not) to follow the moving agent. The agent's eyesight (blindfolded, can see) was included as a fixed within-subject factor in this model. RTs, MTs, and partial choices were analyzed as secondary outcome measures. For these outcome measures, the participant's decision (followed agent, did not follow agent) and the agent's eyesight (blindfolded, can see) were included as fixed within-subject factors.

For trials in which the two agents looked in opposite directions, the primary measure of interest was the participant's decision to follow the seeing agent (as opposed to the blindfolded agent). For this measure, only the intercept was included in the model. In the models for RTs, MTs, and partial choices, the participant's decision (followed seeing agent, followed blindfolded agent) was included as a fixed within-subject factor.

Results

Confirmatory Analysis

Confirmatory Analysis for Trials in Which One Agent Moved.

Reaction Times on Forced-Choice Trials. The RT analysis revealed a main effect of congruency, $F(1, 93) = 130.74$, $p < .001$, $b = 20.10$, 95% CI [16.61, 23.60]. Participants were faster when the moving agent made a congruent movement ($M = 597$ ms, $SD = 118$ ms) compared to an incongruent movement ($M = 637$ ms, $SD = 128$ ms). There was no significant effect of the moving agent's sight, $F(1, 9975) = 0.17$, $p = .681$, $b = 0.65$, 95% CI [-2.47, 3.77]. There was no significant interaction between the agent's congruency and sight, $F(1, 9974) = 0.43$, $p = .514$, $b = -1.04$, 95% CI [-4.16, 2.08], on RTs, suggesting that the congruency effect did not differ for the seeing versus blindfolded agent. Figure 3A shows the congruency effect on RTs for the blindfolded and seeing agent.

Error Rates on Forced-Choice Trials. The ER analysis (Figure 3B) revealed a significant effect of congruency on ERs, *z* = 5.32, *p* < .001, *OR* = 1.80, 95% CI [1.45, 2.23], with more errors for incongruent (*M* = 2.73%, *SD* = 3.91%) than congruent (*M* = 0.87%, *SD* = 1.64%) movements by the moving agent. There was no significant main effect of the moving agent's sight, *z* = 1.33, *p* = .185, *OR* = 1.13, 95% CI [0.95, 1.34], and no significant interaction between congruency and sight of the agent, *z* = 1.12, *p* = .265, *OR* = 0.91, 95% CI [0.76, 1.08].

Movement Times on Forced-Choice Trials. There was no significant effect of congruency on MTs, *F*(1, 10046) = 3.74, *p* = .053, *b* = -2.60, 95% CI [-5.24, 0.04]. Note that, numerically, this effect showed faster MTs for incongruent (*M* = 635 ms, *SD* = 143 ms) compared to congruent movements (*M* = 640 ms, *SD* = 146 ms), a pattern opposite to the significant congruency effects found in our primary outcome measures. There was no significant effect of the agent's sight, *F*(1, 10045) = 0.67, *p* = .413, *b* = -1.10, 95% CI [-3.74, 1.54], nor a significant interaction effect, *F*(1, 10045) = 0.09, *p* = .761, *b* = 0.41, 95% CI [-2.23, 3.05], on MTs.

Partial Errors on Forced-Choice Trials. The analysis of partial errors revealed a significant effect of congruency, *z* = 8.45, *p* < .001, *OR* = 1.45, 95% CI [1.33, 1.58]. Participants made more partial errors when the moving agent made incongruent (*M* = 11.09%, *SD* = 9.10%) compared to congruent movements (*M* = 5.68%, *SD* = 4.93%). We further found a significant main effect of the agent's sight, *z* = 2.25, *p* = .025, *OR* = 0.92, 95% CI [0.86, 0.99], with more partial errors when the agent was blindfolded (*M* = 8.93%, *SD* = 6.95%) than when the agent could see (*M* = 7.84%, *SD* = 6.46%). In line with previous outcome measures, the interaction between the agent's congruency and sight was non-significant, $z = 0.50$, $p = .615$, $OR = 1.02$, 95% CI [0.95, 1.09].

The Participant's Decision on Free-Choice Trials. The analysis of the participants' decision (not) to follow the moving agent (Figure 3C) revealed a significant intercept, $z = 7.69$, $p < .001$, $OR = 1.33$, 95% CI [1.24, 1.43]. Participants followed the moving agent in 57.02% (SD = 8.52%) of the trials, which is significantly more than the chance level. There was no significant effect of the moving agent's sight on the participant's decision, $z = 0.27$, $p = .784$, $OR = 1.01$, 95% CI [0.95, 1.07].

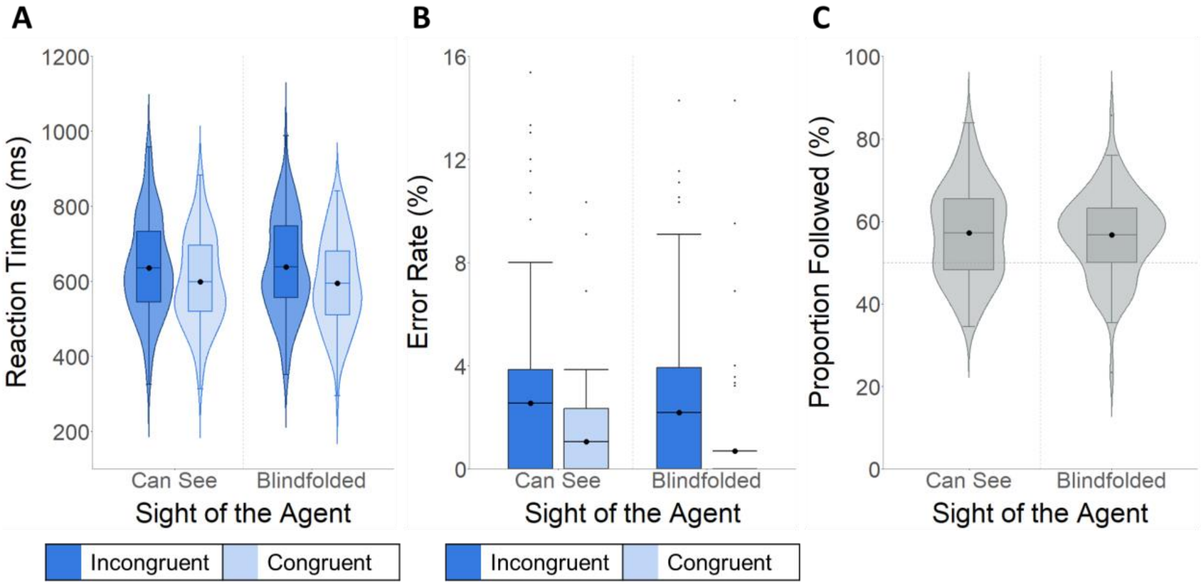
Reaction Times on Free-Choice Trials. There was a significant effect of the participants' decision to follow the agent on RTs, $F(1, 90) = 28.30$, $p < .001$, $b = 17.88$, 95% CI [11.20, 24.55]. Participants had faster RTs when they followed the moving agent (M = 675 ms, SD = 158 ms) than when they did not follow the agent (M = 712 ms, SD = 169 ms). We found no effect of the agent's sight, $F(1, 4937) = 2.09$, $p = .148$, $b = 4.08$, 95% CI [-1.45, 9.62], nor a significant interaction between the participant's decision and the agent's sight, $F(1, 4886) = 0.43$, $p = .511$, $b = -1.87$, 95% CI [-7.43, 3.70].

Movement Times on Free-Choice Trials. There was no significant effect of the participant's decision to follow the agent, $F(1, 89) = 0.07$, $p = 0.797$, $b = -0.55$, 95% CI [-4.76, 3.66], or the sight of the agent, $F(1, 4942) = 0.09$, $p = .759$, $b = -0.61$, 95% CI [-4.54, 3.31], and no significant interaction effect, $F(1, 4890) = 0.12$, $p = .730$, $b = -0.70$, 95% CI [-4.65, 3.26], on MTs.

Partial Choices on Free-Choice Trials. The analysis of partial choices revealed a significant effect of the participant's decision to follow the moving agent on the number of partial choices, $z = 5.88$, $p < .001$, $OR = 1.43$, 95% CI [1.27, 1.61], with fewer direction changes when participants chose to follow the moving agent (M = 5.57%, SD = 5.97%) than when they chose the other target (*M* = 10.42%, *SD* = 9.58%). There was no significant main effect of the moving agent's sight, *z* = 0.05, *p* = .962, *OR* = 1.00, 95% CI [0.90, 1.12], and no significant interaction between the participant's decision and the agent's sight on partial choices, *z* = 0.77, *p* = .442, *OR* = 1.04, 95% CI [0.94, 1.16].

Figure 3

The Congruency Effect on Reaction Times (A) and Error Rates (B) for the Seeing and Blindfolded Agent and the Participant's Decision to Follow each Agent (C) in Trials in Which one Agent Moved



Note. The proportion followed represents the proportion of trials in which the participant decided to follow the moving agent. Reaction times (RTs) are expressed in milliseconds. Error rates (ERs) and the proportion followed are expressed in percentage. The line with the solid dot indicates the mean RT (A), ER (B), and proportion followed (C) across participants for each condition.

Incongruent movements: dark blue (dark grey). Congruent movements: light blue (light grey)

Confirmatory Analysis for Trials in Which the Two Agents Looked in Opposite Directions.

Reaction Times on Forced-Choice Trials. The RT analysis (Figure 4A) revealed no significant effect of the congruency of the seeing agent on RTs, $F(1, 5078) = 0.01$, $p = .927$, $b = 0.20$, 95% CI [-4.16, 4.57], suggesting that participants did not imitate the seeing over the blindfolded agent.

Error Rates on Forced-Choice Trials. The analysis of ERs (Figure 4B) revealed a significant effect of the seeing agent's congruency, $z = 2.83$, $p = .005$, $OR = 1.35$, 95% CI [1.10, 1.66], with fewer errors on congruent ($M = 1.37\%$, $SD = 2.68\%$) compared to incongruent ($M = 2.54\%$, $SD = 3.83\%$) trials. As congruency was anchored to the seeing agent, this indicates that the seeing agent's movements had a stronger influence on the participants' ERs than the blindfolded agent's movements did.

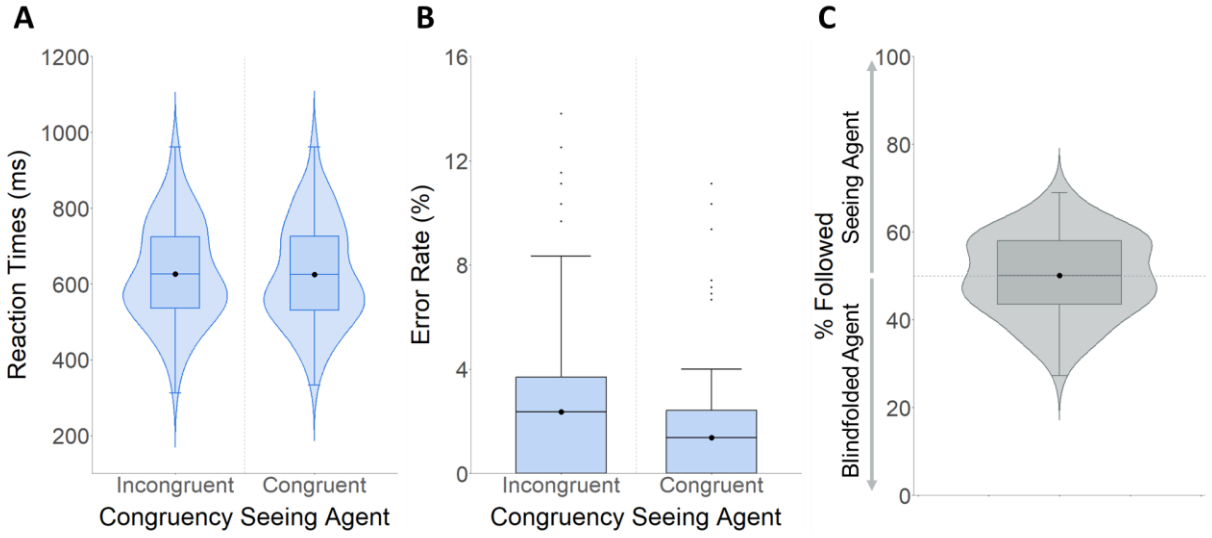
Movement Times and Partial Errors on Forced-Choice Trials. In line with the RT analysis, there was no significant effect of the seeing agent's congruency on MTs, $F(1, 92) = 0.15$, $p = .698$, $b = 0.76$, 95% CI [-3.11, 4.63], or partial errors, $z = 1.61$, $p = .107$, $OR = 1.09$, 95% CI [0.98, 1.21].

Participant's Decision on Free-Choice Trials. The analysis of the participants' decision to follow the seeing agent (Figure 4C) revealed no significant intercept, $z = 0.06$, $p = .953$, $OR = 1.00$, 95% CI [0.93, 1.08], which suggests that the seeing agent was not followed more frequently than the blindfolded agent ($M = 50.06\%$, $SD = 9.31\%$).

Reaction Times, Movement Times, and Partial Choices on Free-Choice Trials. There was no significant effect of following the seeing agent on participants' RTs or MTs, all $F\text{s} \leq 2.20$, all $p\text{s} \geq .138$, nor on partial choices, $z = 0.26$, $p = .791$, $OR = 0.98$, 95% CI [0.83, 1.15]. This suggests that RTs, MTs, and the number of partial choices did not depend on whether participants followed the seeing vs. blindfolded agent.

Figure 4

The Congruency Effect for the Seeing Agent on Reaction Times (A) and Error Rates (B) and the Percentage of Trials in Which the Seeing vs. Blindfolded Agent was Followed (C) in Trials in Which the Two Agents Looked in Opposite Directions



Note. Reaction times (RTs) are expressed in milliseconds. Error rates (ERs) and the number of trials in which the blindfolded vs. seeing agent was followed are expressed in percentage. The line with the solid dot indicates the mean RT (A), ER (B), and percentage of trials in which the seeing vs. blindfolded agent was followed (C) across participants.

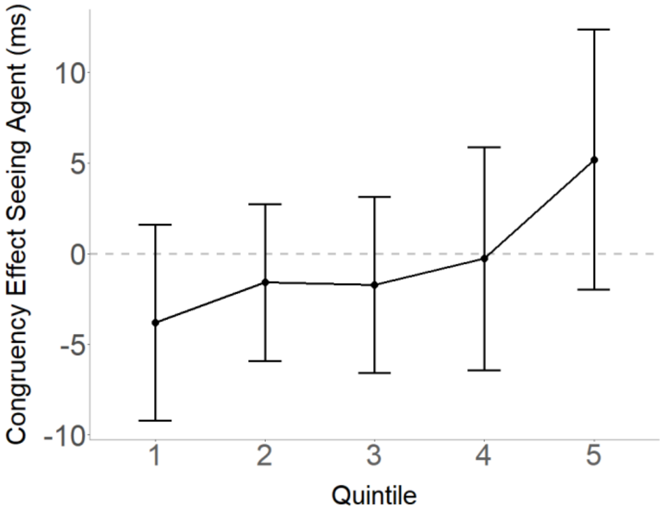
Exploratory Time Course Analysis on Reaction Times

Whereas ERs showed a significant congruency effect for the seeing agent when both agents looked in opposite directions, RTs did not show this effect. A potential explanation for this absence of an RT effect is that the effect depended on the time course of the response. Specifically, given that errors more often occur in trials with fast responses (Rabbitt, 1966), it is possible that the effect of eyesight on imitation was primarily captured by ERs in these early responses, causing the overall RT effect to diminish. However, the RT effect may still be detectable later during the response time course. This would be consistent with previous research suggesting that RT congruency effects become stronger in slower responses (Catmur & Heyes, 2011; Cracco et al., 2015), To test this post-hoc hypothesis, we conducted an exploratory analysis to investigate the impact of the response time course on the congruency effect for the seeing agent on RTs. We ordered the RTs from fastest to slowest separately for each participant and condition (congruent vs. incongruent movement by seeing agent). We saved the ‘rank’ of each RT as a separate variable and added this as a trial-by-trial predictor to the forced-choice RT models in trials with two moving agents. Because adding this predictor violated the normality assumption, we used a generalized mixed-effects model with the Gamma family and the identity link function.

The exploratory time course analysis of the reaction times (Figure 5) revealed a significant effect of RT rank, $z = 141.40$, $p < .001$, $b = 15.27$, 95% CI [15.05, 15.48], and a significant interaction between the congruency of the seeing agent and RT rank $z = 2.59$, $p = .010$, $b = 0.28$, 95% CI [0.07, 0.49]. In line with our post-hoc explanation, this suggests that the RT congruency effect for the seeing vs. non-seeing agent increased positively with RT rank.

Figure 5

The Congruency Effect on Reaction Times for the Seeing Agent in Trials in Which the Two Agents Looked in Opposite Directions for Different Quintiles



Note. The quintiles are groupings of RT ranks, with quintile five representing the highest RT ranks, hence slowest RTs. The error bars indicate the standard errors. The y-axis shows the congruency effect for the seeing agent on RTs and is expressed in ms.

Discussion

We tested the effect of model eyesight on automatic imitation using a VR task. When only one agent looked at one of the target locations, we found that participants showed a tendency to imitate this virtual agent in both forced- and free-choice trials, in line with the results of Cracco et al. (2022). Participants made fewer errors and reacted faster when agents made congruent compared to incongruent movements in forced-choice trials. Furthermore, they followed the agents above chance level in free-choice trials. Regarding the secondary outcome measures, we found a significant congruency effect on partial errors in forced-choice trials, and participants reacted faster and made fewer partial choices when they chose to follow the agents in free-choice trials. The movement times, however, were not influenced by the agents' movements, whereas they did show a small yet detectable effect in the study by Cracco et al. (2022). The absence of an MT effect in this experiment was most likely caused by the smaller sample size compared to Cracco et al. (2022), combined with the changes we made to the original task. More specifically, we moved the target locations further away from the middle of the screen compared to the original paradigm, potentially eliminating the small imitation effect previously found on the movement duration.

With regard to our hypothesis on the effect of model eyesight, we found only limited evidence for the effect of the agents' eyesight on these imitative tendencies; namely, when both agents looked in opposite directions, participants made fewer errors when the seeing agent made a congruent compared to an incongruent movement. This suggests that the movements of the seeing agent had more influence on the participant's ERs than the movements of the blindfolded agent, who moved oppositely. However, model eyesight had no effect on the RT congruency effect or the participant's decision to follow the agents, both when one or both agents moved.

Because the trials in which the agents looked in opposite directions were designed to maximize the probability of finding an effect, it is not surprising that we only found an effect of eyesight in these trials. More specifically, this finding aligns with theories of social judgment (Mussweiler, 2003), stating that comparisons are essential for human judgment. The comparison between both agents is less relevant when only one agent moves, but the differences between both agents do become important when both agents act differently, and the participant is required to select one to follow. The current results might suggest that observing opposite movements is necessary for model eyesight to influence imitation.

However, if this is the case, it is surprising that the agents' eyesight only influenced ERs and not RTs. RTs are typically used as the primary measure of automatic imitation and have not only been found to show stronger automatic imitation effects than ERs, but also seem to be more sensitive to modulators (Cracco, Bardi, et al., 2018). A potential explanation for the absence of a significant RT effect in trials in which both agents looked in opposite directions is that this effect was absorbed by ERs in fast responses (Rabbitt, 1966), thereby diminishing the overall RT effect. Previous research suggests that imitation effects on RTs become stronger in slower responses (Catmur & Heyes, 2011; Cracco et al., 2015), hence the effect might still be detectible in these slower responses. In our exploratory analysis of the RTs, we indeed found that the congruency effect for the seeing agent became stronger later during the time course, which suggests that the effect of eyesight on RTs relied on both the presence of conflicting movements and the timing of the response. However, note that the mean RT effect was visually absent or even negative in the faster responses and only (visually) slightly positive in the slowest responses (see Figure 5).

Regarding the absence of an effect of eyesight in free-choice trials, it is noteworthy that the overall imitation effect in this study was also smaller in free- compared to forced-choice trials. This could suggest that, whereas free-choice trials may intuitively resemble real-life imitation more closely, they might not capture imitative tendencies as effectively as forced-choice trials do. Consequentially, detecting the social modulation of this smaller imitation effect also becomes more difficult. However, whereas it could be that free-choice trials captured imitation and its social modulation less effectively, this does not explain why the congruency effect on partial errors was not influenced by the agents’ eyesight. There was, however, a visual difference of about 1% in partial errors between congruent and incongruent trials, but this difference did not reach significance (*p* = .107). A potential explanation for this is that the seeing agent’s movements did have a stronger influence on partial errors than the blindfolded agent’s movements, but that this effect was too small to be detected with the current sample size.

Altogether, these findings put constraints on the influence of eyesight on imitation. First, whereas we found some evidence for an effect of eyesight on ERs and RTs in forced-choice trials with two moving agents, we found no effect on the participant's decision to follow the agents in free-choice trials. Second, the effect on both ERs and RTs depended on very specific conditions. More specifically, the effect of model eyesight was significant solely in trials in which the two agents made conflicting movements. Moreover, the post-hoc analysis suggests that the timing of the response could modulate the effect on RTs. Third, we found no significant eyesight effect on any of our secondary outcome measures in both free- and forced-choice trials.

An explanation for the limited effects of model eyesight is that our paradigm was still not realistic enough to elicit real-life social effects consistently. Because the participant's task was to detect fires in buildings, obtaining social reward from the virtual agents might be less important in this context. Moreover, imitation was never socially rewarded during the task. Although we increased the ecological validity of the imitation-inhibition paradigm, the virtual agents never interacted with participants and never provided any reaction to imitation. If imitation is indeed driven by its social consequences (Stel et al., 2016; Wang & Hamilton, 2012), social factors will only influence imitation when there is a possibility of positive consequences. In other words, explicit social reward might be necessary for social factors, including model eyesight, to influence imitation. Although social reward is at the core of motivational theories (Stel et al., 2016; Wang & Hamilton, 2012), which state that we imitate because this leads to social reward, no studies have yet tested if automatic imitation increases when it explicitly leads to social reward.

To test this alternative explanation, we conducted a second experiment, in which we manipulated social reward directly and changed our task setting to represent a more socially relevant situation.

Experiment 2

In a second experiment, we adapted the task from Experiment 1 to include social reward and social punishment related to imitation. By doing so, we tested the effect of model eyesight and social reward simultaneously while further increasing the task's ecological validity. Participants were placed in a virtual art gallery together with two virtual agents and looked at a left or right painting when they heard a tone, similar to forced-choice trials in Experiment 1. As a manipulation of social reward, the agents reacted to the participant's responses during the task. One agent liked imitation: they smiled at the participant if they looked at the same painting as them and looked angrily at the participant when they looked at the other painting. The other agent reacted oppositely: they disliked being imitated and liked it when participants chose a different painting.

Only forced-choice trials in which one agent moved were included in this experiment to obtain sufficient power with a realistic number of trials. We chose to remove free-choice trials because they did not seem to capture imitative tendencies as well as forced-choice trials in Experiment 1. We removed trials in which both agents moved because the potential effects of model eyesight and social reward were uninterpretable without additional conditions. However, including those additional conditions would lead us to exceed the maximum number of trials possible with this paradigm, compromising the experiment's feasibility.

If the agent liked imitation, we expected participants to show a stronger congruency effect when the agent could see compared to when they were blindfolded. Because the agent only reacted when they could see, the agent's eyesight indicated when imitation would be socially rewarding. However, when the agent reacted negatively to imitation, we did not expect participants to show a stronger congruency effect when the agent could see, as imitation was socially punished in this condition. Here, we had no specific hypothesis. It could be that participants show less automatic imitation when the agent sees, but it was also possible that the agent's eyesight would not influence automatic imitation, as imitation was never socially rewarding.

Method

Participants

A new participant sample was recruited through the research participation system of Ghent University (Sona Systems) and social media posts. One hundred twenty participants took part in this experiment from October 2023 to January 2024 and were reimbursed €10 for their participation. Two participants experienced dizziness during the VR task. The final five trials were removed from the data of one participant and data from the second block were removed for the other participant. Two participants were excluded before any further data processing, because they were not fluent in Dutch. The data of one additional participant had to be removed due to a technical error during the VR task. After further preregistered exclusions (see the Analysis section for details), the final sample consisted of 110 participants for the analysis (90 female, 20 male, $M_{\text{age}} = 22.65$, $SD_{\text{age}} = 3.92$). All included participants had normal or corrected-to-normal vision, were Dutch-speaking, and were naïve to the purpose of the experiment. Participants signed an informed consent before the start of the procedure.

We conducted a simulation power analysis (Kumle et al., 2021) based on Experiment 1 data. We aimed to find similar congruency effects on RTs and ERs, which corresponded to an estimated congruency effect of 40 ms for RTs and 2% for ERs. We divided these effects by two and four to obtain an estimate for the two-way and three-way interaction effects respectively (Baranger et al., 2023). The power analysis indicated that a sample of 110 participants would allow us to detect these effects with ≥ 80% power and a significance threshold of 0.05.

Task and Procedure

The study took place in the Faculty of Psychology and Educational Sciences at Ghent University (Belgium). The VR environment was constructed in Unity Engine (version 2019.4.29f), using the “Apartment Kit” assets from Brick Project Studio (2023). Participants received verbal instructions about the experiment before the start of the task.

Learning Phase. Participants first completed a learning phase, which consisted of 20 trials, divided into two blocks of 10 trials. This phase was added for participants to learn the reactions of the agents associated with the participant’s choices. Participants stood in a virtual art gallery facing either the female or male agent. Behind this agent and in the middle of the setup, there was a large painting, which served as the equivalent of a fixation cross. The walls left and right of the participant contained a painting of abstract figures. The paintings changed across trials and were used as target locations in the imitation task. To create different paintings, we selected 41 images from the stimulus set from Aminoff et al. (2007). This stimulus set contains colorful arbitrary shapes with no apparent affective value on a black background. Each trial started with a variable period from 3000 to 4500 ms, after which a non-directional tone was played with a total duration of one second. This tone indicated that participants had to look at either the left or right painting, but participants were free to choose in which of the two directions to look. The paintings were outside the participant’s view when they looked at the painting in front of them, hence they did not know what the paintings looked like before they made a head movement. Zero to 100 ms after the start of the tone, the agent in front of them also looked at one of the paintings. Before the start of the task, participants were informed that the agent would look at their favorite painting. In reality, the agents’ gaze direction was random. Participants could respond from the start of the auditory cue until the response deadline of 3000 ms. When the participant’s gaze reached one of the target paintings, the painting slowly faded to black to indicate that their response was registered. When participants looked back at the center of the screen, in the direction of the agent, the agent provided an emotional reaction to the participant's response. This reaction had a duration of about 3000 ms and was included in the inter-trial interval, which is why the inter-trial interval is longer compared to Experiment 1.

One agent reacted positively to being imitated and negatively to not being imitated. More precisely, this agent smiled at the participant when the participant chose the same painting as them and looked angry after the participant chose the other painting. The other agent reacted oppositely. This agent looked angry when participants chose the same painting and smiled when they chose the other painting. Before the start of the task, participants were informed that the virtual agents would react to their choices and that one agent liked being followed, whereas the other did not.

After the first block of ten trials, participants repeated the task together with the other agent. Both the presentation order of the agents and the reactions linked to each agent were counterbalanced across participants.

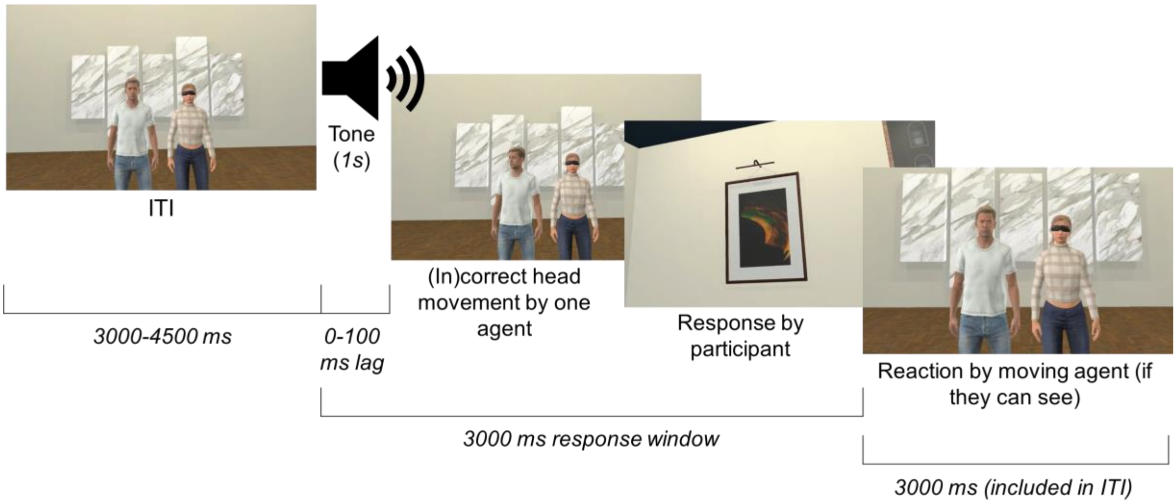
Practice and Test Phase. After the learning phase, participants were informed that both agents would be present during the next task, with one wearing a blindfold. They were further told that their task would change, whereas the agents would still look at their favorite painting if they could see. If an agent was blindfolded, they would randomly look left or right when hearing a tone. Participants first completed eight practice trials with auditory accuracy feedback, which they could repeat, if necessary, before proceeding to the test phase. The test phase contained 256 trials without accuracy feedback, divided into four blocks of 64 trials each. All eight conditions were randomized within each block.

Except for the agents’ emotional reactions to the participant’s choice, the task during the test phase (see Figure 6 for an example trial) was almost identical to the forced-choice trials in Experiment 1 in which one agent moved. In the test phase, participants could no longer choose where to look but had to react based on the tone they heard. Two different tones, a high tone and a low tone, were used to cue the correct response. One tone indicated that participants had to make a head movement toward the left painting. The other tone indicated that they had to look at the right painting. The sound-response mapping was counterbalanced across participants.

Both virtual agents stood in front of the participant during the test phase. The position of these agents (i.e., left or right) was counterbalanced across participants. In each block, one agent wore a blindfold. Identical to Experiment 1, the agent wearing the blindfold was alternated across blocks, and the agent who was blindfolded first was counterbalanced across participants. Zero to 100 ms after the start of the tone, one agent looked at one of the two target paintings, either the correct (congruent trial) or incorrect (incongruent trial) painting. If the agent could see, they reacted to the participant’s responses like they did during the learning phase. Blindfolded agents never reacted to the participant’s response. Hence, in each trial, the moving agent differed based on their eyesight (blindfolded, can see), their attitude toward imitation (likes imitation, dislikes imitation), and their movement congruency (congruent, incongruent).

Figure 6

Example Trial in the Test Phase of Experiment 2 from Participant Viewpoint



Note. The duration of the auditory cue was one second, which means that the sound was still playing during the head movement by the agent. The final image is zoomed-in to make the negative reaction more visible. If the agent reacted in the previous trial, this reaction was included in the inter-trial-interval (ITI).

After the VR task, participants provided their demographic information (age and gender) and completed several questionnaires on a laptop. To indicate their gender, participants could choose between “male”, “female”, “non-binary”, “not listed”, or “prefer not to say”. If they indicated that their gender was “not listed”, they could provide an alternative. Participants completed the AQ (Baron-Cohen et al., 2001) and the NTBS (Leary et al., 2013) in a randomized order. The materials, analysis, results, and discussion for the analysis of the questionnaires are available in the Supplementary Materials (S1).

Finally, participants completed three manipulation checks. First, they were asked how each virtual agent reacted to their movements when the agent could see. Participants received a picture of each agent along with questions about how the agent reacted when the participant looked at the same painting (question 1) or a different painting (question 2). They could choose between the options “this person looked happy”, “this person looked angry”, and “I do not know”. Then, participants were asked if they believed the agents could (not) see when blindfolded and whether they felt like they followed one agent more often than the other. Finally, participants provided their payment information and could share their e-mail address if they wished to receive a summary of the study results.

Analysis

Calculation of the Outcome Measures and Participant and Trial Exclusions

The primary and secondary outcome measures, along with their calculations, were identical to those used in the forced-choice trials of Experiment 1. More specifically, the primary outcome measures were RTs and ERs, and partial errors and MTs were included as secondary outcome measures. Participant and trial exclusions were preregistered on the OSF (https://osf.io/9e28j/?view_only=0bd084c5273043e28c175f6d14350fb7).

Seven participants were excluded from all analyses because their ER during the test phase trials was ≥ 40% (none), because their ER exceeded the average ER in the sample with ≥ 2.5 *SD* (five participants), or because their mean RT was ≥ 2.5 *SD* above or below the mean RT in the sample (two participants). One hundred and ten participants (90 female, 20 male, M_{age} = 22.65, SD_{age} = 3.92) were included in the analysis.

The criteria for trial exclusions were identical to the criteria in Experiment 1. Trials were excluded from all analyses if the RT was ≤ 200 ms (1.60%), if the RT was ≥ 4000 ms (0.00%), or if the MT was ≥ 2000 ms (0.00%). In the RT/MT analysis, trials were excluded if the RT and/or MT was ≥ 2.5 *SD* above or below the participant’s mean RT/MT (3.54%), if the response was incorrect (0.57%), or if a partial error was made (8.52%). The same criteria were used in the partial error analysis, except that the partial errors were included, and in the forced-choice ER analysis, except that the errors were included. Hence, trials were excluded from the error (3.17%) and partial error (3.65%) analysis if the RT and/or MT was ≥ 2.5 *SD* above or below the participant's mean RT/MT.

Preregistered Data Analysis. Apart from the included within-subject factors, the models, the selection of the random-effects structure, and the reported statistics are identical to Experiment 1. The moving agent's eyesight (blindfolded, can see), attitude toward being imitated (likes imitation, dislikes imitation), and movement congruency (congruent, incongruent) were included as fixed within-subject factors in the linear mixed-effects models for RTs and MTs, and the generalized mixed-effects models for ERs and partial errors. Results for the MT analysis are reported in the Supplementary Materials (S2), because this measure showed no significant congruency effect in Experiment 1.

Results

Manipulation Checks

Of the participants who were not excluded based on other exclusion criteria, 14 participants (12.73%) failed the manipulation check. This means that these participants made at least one mistake or indicated "I do not know" when indicating how the agents reacted. We did not exclude these participants from the analyses, but added whether they failed the manipulation check as a between-subject factor in an exploratory analysis instead, as mentioned in the preregistration. However, in this exploratory analysis, failing vs. passing the manipulation check had no significant effect on RTs, ERs, or partial error results.

Ninety-two participants (83.64%) indicated they believed the blindfolded person could not see them. Fifteen participants indicated that they believed the blindfolded person could still see during the task (13.64%). The remaining three participants wrote that they felt like the person could see them at the start, but not anymore after a while (1 participant) or felt like the virtual person could somehow “sense” where they looked (2 participants). Only including participants who indicated they believed the blindfolded person could not see them did not change the results.

The third question, which asked if participants felt they followed one agent more often than the other, was exploratory and its responses were not used for any further analyses. A summary of the participants’ responses can be found in the Supplementary Materials (S3).

Reaction Times

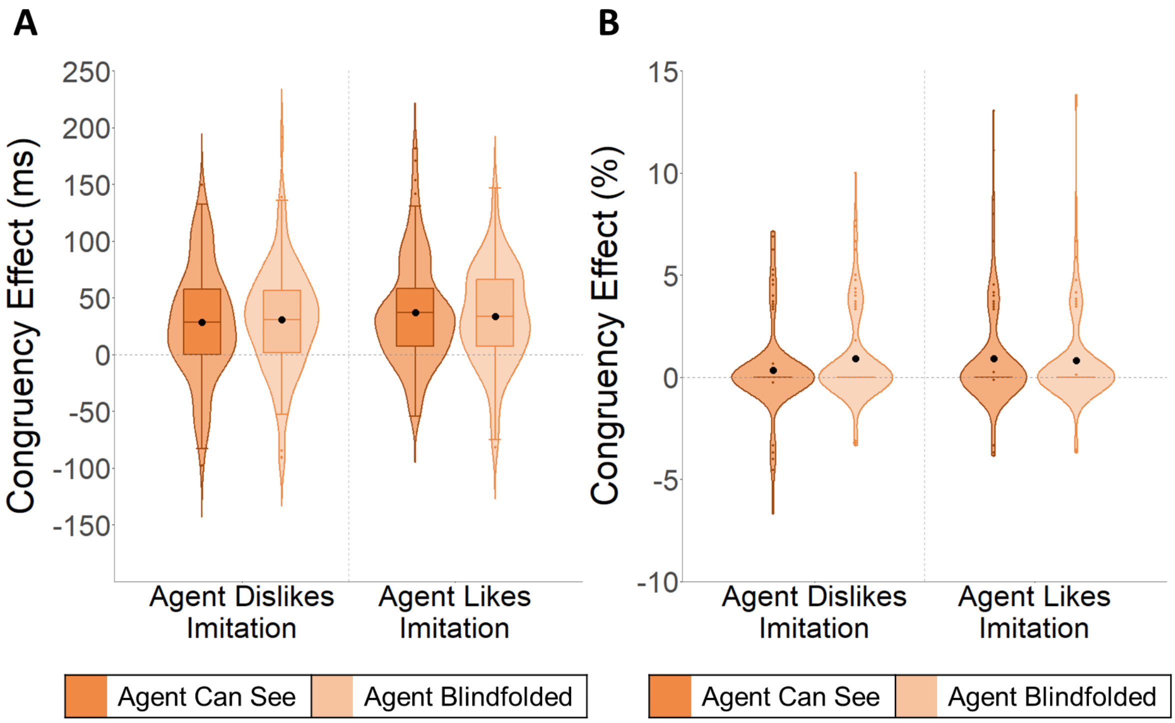
The RT analysis revealed a main effect of congruency, *F*(1, 110) = 163.36, *p* < .001, *b* = 16.21, 95% CI [13.70, 18.72]. Participants were faster for congruent (*M* = 582 ms, *SD* = 97 ms) compared to incongruent (*M* = 615 ms, *SD* = 97 ms) movements by the virtual agents. There was no significant effect of the moving agent’s sight, *F*(1, 329) = 2.19, *p* = .140, *b* = -2.09, 95% CI [-4.86, 0.69], nor their attitude toward imitation, *F*(1, 329) = 0.01, *p* = .920, *b* = -0.14, 95% CI [-2.92, 2.63], on RTs. All two-way interactions were non-significant, all *F*s ≤ 1.53, all *p*s ≥ .216. Importantly, there was no significant three-way interaction between the moving agent’s congruency, sight, and attitude toward imitation, *F*(1, 23497) = 0.52, *p* = .471, *b* = -0.77, 95% CI [-2.86, 1.32], which suggests that the influence of the agent’s eyesight on the RT congruency effect did not differ for the agent who liked versus disliked being imitated. Figure 7A shows the RT congruency effect for the agent who reacted positively vs. negatively to being imitated when they could see and when blindfolded.

Error Rates

The ER analysis (Figure 7B) revealed a significant effect of movement congruency on ERs, *z* = 6.08, *p* < .001, *OR* = 2.09, 95% CI [1.65, 2.65]. Participants made fewer errors on congruent (*M* = 0.23%, *SD* = 0.58%) compared to incongruent trials (*M* = 0.98%, *SD* = 1.47%). There was no significant effect of the agent’s sight, *z* = 0.32, *p* = .747, *OR* = 1.04, 95% CI [0.84, 1.29], or attitude toward imitation, *z* = 0.27, *p* = .784, *OR* = 0.97, 95% CI [0.78, 1.20], on ERs. There were no significant two-way interactions, all *z*s ≤ 1.12, all *p*s ≥ .264. In line with the RT results, the three-way interaction between the agent's congruency, sight, and attitude toward imitation was also non-significant, *z* = 1.66, *p* = .097, *OR* = 0.83, 95% CI [0.67, 1.03]. For the agent who liked imitation, the congruency effect was 0.92% (*SD* = 2.57%) when the agent could see and 0.80% (*SD* = 2.25%) when the agent was blindfolded. For the agent who disliked imitation, the congruency effect was 0.34% (*SD* = 2.15%) when the agent could see and 0.92% (*SD* = 2.23%) when blindfolded.

Figure 7

Effects of the Agent's Sight and Attitude Toward Imitation on the Congruency Effect for the Reaction Times (A) and Error Rates (B)



Note. Reaction times (RTs, A) are expressed in milliseconds. Error rates (ERs, B) are expressed in percentage. The solid dot indicates the mean RT (A) and ER (B) across participants for each condition. Note that the boxplots are invisible on the ER plot, because of very low ER variability.

The agent can see: dark orange (dark grey). The agent wears a blindfold: light orange (light grey)

Partial Errors

In line with the RT and ER analyses, the partial error analysis revealed a significant effect of movement congruency, $z = 13.85$, $p < .001$, $OR = 1.70$, 95% CI [1.57, 1.83].

Participants made more partial errors when the moving agent made incongruent (*M* = 11.53%, *SD* = 8.28%) compared to congruent movements (*M* = 4.72%, *SD* = 4.63%). There were no other significant main effects, *z*s ≤ 1.43, all *p*s ≥ .154, nor two-way interactions, all *z*s ≤ 0.99, all *p*s ≥ .323. The three-way interaction between the moving agent's congruency, sight, and attitude toward imitation was non-significant, *z* = 0.08, *p* = .940, *OR* = 1.00, 95% CI [0.95, 1.05].

Discussion

In line with the results of Experiment 1, participants showed a significant congruency effect on RTs and ERs. Participants reacted faster and more accurately for congruent compared to incongruent movements by the agents. However, the congruency effect did not differ based on the attitude of the agent toward imitation or the agent's eyesight. Most importantly, the three-way interaction was also non-significant, which suggests that there was no difference in the influence of the agent's eyesight for an agent who liked being imitated compared to an agent who disliked being imitated. In a similar vein, we found a significant congruency effect for the partial errors, with more partial errors for incongruent movements, but no effect of the agents' reactions nor their eyesight on the congruency effect.

General Discussion

According to motivational theories, humans imitate each other during social interaction because imitation leads to positive social consequences (Stel et al., 2016; Wang & Hamilton, 2012) and thereby supports successful social interaction (Lakin et al., 2003). Whether the other person sees the imitator determines if imitation can lead to such positive consequences. However, whereas some studies indeed found more imitation when a model looked directly at versus away from the participant (Wang et al., 2011; Wang & Hamilton, 2014), others failed to find this effect (Carr et al., 2021; Farmer et al., 2021). The current study investigated the social modulation of automatic imitation in two experiments. Both experiments used a VR task to investigate the effect of model eyesight (Experiment 1, Experiment 2) and social reward (Experiment 2) in a more ecologically valid setting.

In Experiment 1, we tested the effect of model eyesight on automatic imitation using free-choice and forced-choice trials in which one agent moved or both agents moved oppositely. We found only limited evidence for the effect of model eyesight on automatic imitation, as only one outcome measure (ERs) showed a significant effect. That is, when the blindfolded and seeing agent made opposite movements, participants made more errors for incongruent compared to congruent movements by the seeing agent. In the same trials, we performed a post-hoc time-course analysis on RTs and found that the RT congruency effect for the seeing agent increased with slower RTs. However, the congruency effect was only (visually) positive for very slow RTs, whereas it was visually zero or negative for faster RTs. A potential explanation for these limited effects is that our task in Experiment 1 was not social enough, causing participants to have no true expectation of social reward during the experiment. To test this alternative explanation, we conducted a second experiment with a more socially relevant task and a direct manipulation of social reward associated with imitation. However, we found no effect of model eyesight nor social reward on the RT, ER, or partial error congruency effect in the second experiment. Especially the absence of an effect of social reward was surprising, as this prediction is central to motivational theories of imitation (Stel et al., 2016; Wang & Hamilton, 2012).

There are several possible explanations for the absence of the model eyesight effect in the second experiment. The significant eyesight effect in Experiment 1 was found in ERs in trials in which both agents looked in opposite directions. There, the agent who could see caused a stronger ER congruency effect than the blindfolded agent. First, overall, the systematic variance in ERs was rather low. Therefore, it may be useful for future studies to increase systematic variance in ERs by, for example, raising task difficulty or implementing a stricter response window, while ensuring limited potential data loss at the same time. Second, we omitted trials in which both agents looked in Experiment 2 because they were not interpretable without the inclusion of extra conditions. However, these trials may be necessary for imitation to be socially modulated. If this were the case, this would imply that the influence of model eyesight is not only small, but also restricted to very specific conditions. Importantly, we found no effect of the social reward manipulation on imitation in Experiment 2. Indeed, there was no difference in automatic imitation for an agent who disliked imitation compared to an agent who liked imitation. If automatic imitation is not modulated by social reward, it is unlikely that model eyesight would have any effect, as this effect depends on (the expectation) of social reward. Furthermore, the addition of a social reward should have strengthened the effect of model eyesight in Experiment 2, as model eyesight now clearly predicted reward or punishment, even without opposite movements by the agents. One could argue that the social reward manipulation might not have been salient enough. This seems unlikely, as the majority of participants were able to indicate which agent reacted positively vs. negatively to imitation in our manipulation check of Experiment 2. However, we did not ask whether participants liked or disliked these emotional reactions. Hence, we cannot fully exclude the possibility that the reactions were not socially rewarding or punishing (enough) to participants, thereby limiting their influence on imitative tendencies.

In line with our results, previous studies also found that the effects of social factors on automatic imitation in the typical imitation-inhibition task are often absent (De Souter et al., 2021; Genschow et al., 2021; Nevejans & Cracco, 2022) or small (e.g., Newey et al., 2019), potentially caused by the limited ecological validity of this task. In that regard, it could be that our paradigm was still not realistic enough to elicit real-life social effects consistently. Indeed, whereas previous research suggests that participants tend to act similarly in VR as they would in real life (Kinateder & Warren, 2016; Moussaïd et al., 2016), our task was still a rather artificial trial-by-trial task. Furthermore, the virtual characters looked like humans, but participants could still tell they were computer-generated, which has been shown to diminish the strength of their influence on participant behavior (Durnez et al., 2020). Therefore, we can only conclude that social factors do not influence imitative tendencies in this task. It could be that imitation is influenced by social factors in different settings, such as more real-life interaction tasks (Chartrand & Bargh, 1999). Future research could improve immersion by, for example, making the virtual agents more realistic and creating more interactive tasks that resemble real-life social interactions more closely.

Alternatively, the limited effect of model eyesight could imply that automatic imitation is habitual behavior. Habitual behavior is thought to be automatically triggered by a stimulus based on a learned association (for a review, see Gardner, 2015) and persists even when it no longer leads to the valued outcome (Neal et al., 2011). In line with this idea, automatic imitation of observed actions typically occurs without social reward (e.g., Brass et al., 2000; Cracco, Bardi, et al., 2018; Wang et al., 2011; Wang & Hamilton, 2014). In the current study, participants did not only show automatic imitation without explicit social reward (Experiment 1), but even when imitation led to social punishment (Experiment 2). If humans imitate irrespective of social reward, the influence of social factors determining the probability of such reward after imitation will also be limited. Whereas one could argue that this suggests that automatic imitation is innate, there is evidence that it is acquired throughout development (Mukai et al., 2024), in line with the ASL model (Catmur et al., 2009). Hence, imitative tendencies most likely develop over time but could become too stimulus-driven to be modulated by social context. However, more research is needed to confirm this hypothesis. For example, future research could take a developmental approach by comparing the social modulation of imitation across different stages of development to see if this behavior becomes more resistant to modulation over time. Alternatively, future research could test whether more naturalistic factors still influence automatic imitation. In the current experiments, the manipulations and behaviors were relevant only within the task context, which might have limited the social influence on imitation. However, some behaviors have intrinsic meanings, that extend beyond the experimental setting. For example, automatic imitation seems to decrease for anti-social movements (e.g., showing a middle finger) compared to pro-social movements (e.g., showing a thumbs up) (Cracco, Genschow, et al., 2018; but see Farmer et al., 2021, experiment 4). Finally, observing behavior in the absence of social reward or even in the presence of social punishment does not necessarily exclude the possibility that it is goal-directed rather than habitual (in the sense of stimulus-driven). For instance, the behavior could still be directed at other, still valued goals (e.g., participants still believed that the agents' gaze direction helped them optimize task performance, regardless of the given instructions; De Houwer et al., 2018).

Finally, it is important to note that the participants in our experiments were predominantly (first-year psychology) students at Ghent University, which could have influenced the generalizability of the results. Additionally, our research materials were deliberately tailored to a Flemish population, by using virtual agents with a Caucasian appearance as stimuli. These factors should be considered in the interpretation of the results, and we encourage future research to test whether these findings generalize to other populations.

To conclude, we replicated the imitation effects found in previous research on automatic imitation (Cracco, Bardi, et al., 2018; Cracco et al., 2022) in VR, but found no convincing evidence for the modulation by the agents' eyesight and, importantly, no effect of social reward or punishment on imitation. Indeed, the effect of model eyesight was restricted to specific conditions and aspects of imitative behavior in Experiment 1 and there was no significant influence of social factors in Experiment 2. Altogether, these findings challenge the claims of motivational theories about the influence of social reward and model eyesight on automatic imitation. Although the absence of (consistent) social modulation could be related to certain aspects of the employed tasks, these findings prompt us to consider that automatic imitation could be a habitual behavior.

Author Contribution Statement

MN: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing - Original Draft, Writing - Review & Editing, Funding acquisition. **JRW**: Conceptualization, Methodology, Supervision, Writing - Review & Editing, Funding acquisition. **JDH**: Conceptualization, Methodology, Supervision, Writing - Review & Editing, Funding acquisition. **EC**: Conceptualization, Methodology, Supervision, Writing - Review & Editing, Funding acquisition.

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Supplementary Material

Supplementary Material 1: Relation Between Personality Traits and Imitation

In an exploratory analysis, we tested how relevant personal traits influenced the effect of model eyesight on imitation. First, motivational theories assume that imitation is driven by a person's motivation to obtain social reward. Because model eyesight determines whether imitation can lead to such a reward, individuals with higher social motivation should be more sensitive to this cue. To test this prediction, we measured participants' sensitivity to social reward via two questionnaires: the Social Reward Questionnaire (SRQ, Foulkes, 2014) and the Need to Belong Scale (NTBS, Leary, 2013). Participants who are more motivated to obtain social reward should show stronger automatic imitation of the seeing but not the blindfolded agent than participants with lower social motivation. Second, motivational theories suggest that individuals with autism show less influence of social factors on imitation (Forbes et al., 2017; Wang & de Hamilton, 2012). As a preliminary test of this prediction, we tested the relation between the effect of model eyesight on imitation and the participants' autism traits, measured via the Autism Spectrum Quotient (AQ, Baron-Cohen et al., 2001).

Experiment 1

Method

Participants. In the exploratory analysis of the questionnaires, an additional participant was excluded because they told the experiment leader that their level of Dutch was not sufficient to understand all items in the questionnaires.

Materials for the Exploratory Analysis.

*Autism Spectrum Quotient***.** The Dutch version of the AQ (Baron-Cohen et al., 2001; Hoekstra et al., 2008) was included as a measure of autism traits in a neurotypical population. The AQ contains 50 items, equally divided into five subscales: communication, social skills, imagination, attention to detail, and attention switching. Participants responded by indicating how much they agree with each statement on a four-point Likert scale, with the options "definitely agree", "agree", "disagree", and "definitely disagree".

Social Reward Questionnaire. We included the Dutch translation of the SRQ (Foulkes et al., 2014; Smeijers et al., 2022) as a measure of sensitivity to social reward. The SRQ consists of 23 statements within six subscales: admiration (4 items), negative social potency (5 items), passivity (3 items), prosocial interactions (5 items), sexual relationships (3 items), and sociability (3 items). We omitted the sexual relationships subscale because this subscale was not relevant to the current research question and would lead to the unnecessary collection of personal data. Participants scored the 20 remaining statements in the SRQ on a five-point Likert scale with the options ranging from "disagree strongly", "disagree", "neither agree nor disagree", "agree", and "agree strongly".

Need To Belong Scale. The NTBS (Leary et al., 2013) was added as a second measure of sensitivity to social reward and consists of 10 items related to the motivation to affiliate with others. We used a self-translated version of the scale. Participants scored each item on a five-point Likert scale with the same options as the SRQ.

Analysis. We tested whether the effect of model eyesight on imitation correlated with participants' scores on the AQ, the SRQ subscales, and the NTBS. To do so, we calculated the Spearman correlation coefficient between the participant's scores on the questionnaires and the effect of model eyesight on imitation via RTs, ERs, and the participant's decision (not) to follow the agent's gaze in the VR task. These three correlational analyses were performed on the outcome measures in trials in which one agent moved and trials in which the two agents looked in opposite directions, resulting in six separate correlational analyses. We corrected the p-values (indicated with p_{adj} below) for multiple comparisons via Benjamini-Hochberg's false discovery rate (Benjamini & Hochberg, 1995) within each of these six correlational analyses.

Results

Trials in which One Agent Moved. There were no significant correlations between the imitation effect for the seeing agent on the main outcome measures and the AQ scores, all $|r_s| \leq .22$, all $p_{adj} \geq .265$, NTBS scores, all $|r_s| \leq .17$, all $p_{adj} \geq .516$, or SRQ scores, all $|r_s| \leq .17$, all $p_{adj} \geq .346$. All correlations for trials in which one agent moved can be found in Table S1.

Trials in Which the Two Agents Looked in Opposite Directions. There were no significant correlations between the imitation effect for the seeing agent on the main outcome measures and the questionnaires, all $|r_s| \leq .19$, all $p_{adj} \geq .295$. Table S2 presents an overview of all correlations in trials with two moving agents.

Table S1

Correlations Between the Questionnaire Scores and the Effect of Eyesight on the Imitation for the Main Outcome Measures in Trials in Which One Agent Moved

	Congruency x eyesight effect on reaction times	Congruency x eyesight effect on error rates	Eyesight effect on participant's decision to follow the moving agent
Autism Spectrum Quotient	-.22	.07	-.02
Need to Belong Scale	-.08	-.17	-.09
SRQ: Negative Social Potency	-.17	.05	.08
SRQ: admiration	-.14	.05	.00
SRQ: sociability	.08	-.07	.00
SRQ: passivity	.05	.15	-.01
SRQ: prosocial interaction	.02	.07	-.07

Note. * *p* < .05, ** *p* <.01, *** *p* < .001. SRQ stands for Social Reward Questionnaire.

Table S2

Correlations Between the Questionnaire Scores and the Imitation Effect for the Seeing Agent on Main Outcome Measures in Trials in Which the Two Agents Looked in Opposite Directions

	Seeing Agent's Congruency effect on reaction times	Seeing Agent's Congruency effect on error rates	Participant's decision to follow seeing agent
Autism Spectrum Quotient	-.01	-.03	.01
Need to Belong Scale	-.01	.11	-.05
SRQ: Negative Social Potency	-.10	.19	.08
SRQ: admiration	-.10	.12	-.12
SRQ: sociability	.04	.18	-.04
SRQ: passivity	-.16	.01	-.06
SRQ: prosocial interaction	.13	-.14	.08

Note. * $p < .05$, ** $p <.01$, *** $p < .001$. SRQ stands for Social Reward Questionnaire.

Experiment 2

Method

Participants. All 110 participants (90 female, 20 male, $M_{\text{age}} = 22.65$, $SD_{\text{age}} = 3.92$) from the confirmatory analyses were included in the exploratory correlational analysis.

Materials for the Exploratory Analysis. The SRQ was not included in Experiment 2. The other questionnaires were identical to the questionnaires included in Experiment 1.

Analysis. We calculated the Spearman correlation coefficient between the participant's scores on the questionnaires and the interaction effect of model eyesight and the model's attitude toward imitation via RTs and ERs. We corrected the p-values (indicated with p_{adj} below) for multiple comparisons via Benjamini-Hochberg's false discovery rate (Benjamini & Hochberg, 1995) for the RT and ER analysis separately.

Results

There were no significant correlations between the AQ-scores, $r(108) = .14$, $p_{adj} = .309$, or NTBS-scores, $r(108) = .01$, $p_{adj} = .933$, and the interaction effect on RTs. Likewise, there was no significant correlation between the AQ-scores, $r(108) = .06$, $p_{adj} = .984$, or NTBS-scores, $|r(108)| < .01$, $p_{adj} = .984$, and the ER interaction effect.

Discussion

In the exploratory analyses of Experiment 1 and Experiment 2, we tested the relation between social modulation of imitation and personality traits. For Experiment 1, we tested whether there is a relation between the effect of eyesight on imitative tendencies and reward sensitivity and autism traits. We found no significant correlations between the effect of eyesight on imitation and participants' scores on measures of social reward sensitivity, or autism traits. For Experiment 2, we tested whether the interaction effect between the agent's eyesight and the attitude of the agent toward imitation correlated with the need to belong and autism traits. In line with the results of Experiment 1, there were no significant correlations.

Importantly, previous research also failed to find a relation between personality traits and automatic imitation (Darda et al., 2020; Genschow et al., 2017), suggesting that personality does not influence automatic imitation. However, the absence of a relation between the effect and autism traits could also be related to the sample in the current study. Similar to our study, Prinsen et al. (2017, 2018, 2019) investigated the relation between autism traits, measured via the Social Responsiveness Scale (Constantino & Todd, 2005), and the modulation of motor excitability by eye gaze. They also failed to find a relationship between modulation by eye gaze and autism traits in some of their studies (Prinsen et al., 2017, 2018) and argued that this could be due to a lack of heterogeneity in their sample (Prinsen et al., 2017). This could also be true for our study, as the majority of our sample consisted of (first-year psychology) students. Hence, we might need a more heterogeneous or even clinical (e.g., Forbes et al., 2017) sample to detect the influence of autism (traits) on imitation.

Supplementary Material 2: Movement Time Analysis Results

There was no significant effect of movement congruency, *F*(1, 23540) = 0.12, *p* = .725, *b* = 0.34, 95% CI [-1.54, 2.21], the moving agent’s sight, *F*(1, 325) = 0.07, *p* = .794, *b* = 0.27, 95% CI [-1.77, 2.32], nor their attitude toward imitation, *F*(1, 325) = 0.02, *p* = .890, *b* = -0.14, 95% CI [-2.19, 1.90], on MTs. All two-way interactions were non-significant, all *F*s ≤ 1.00, all *p*s ≥ .317. Importantly, there was no significant three-way interaction between the moving agent’s congruency, sight, and attitude toward imitation, *F*(1, 23582) = 1.19, *p* = .275, *b* = -1.04, 95% CI [-2.92, 0.83], which means that there were no differences in the eyesight effect for agents who liked versus disliked being imitated.

Supplementary Materials 3: Summary of Participants' Responses to the Third Question

The majority of participants in Experiment 2 (57.27%) indicated they did not follow one agent more often than the other. Of the participants who indicated they felt like they had followed one agent more often, five participants (4.55% of all participants) filled in that "it depended on the blindfold". As the remaining answers are only interpretable if we include which agent reacted positively for that participant, we will report answers separately based on whether the female or male agent reacted positively to imitation.

When the female agent reacted positively, 13 participants (11.81%) indicated they followed her more, whereas seven participants (6.36%) indicated they followed the male agent – who disliked imitation – more often. When the male agent liked imitation, 17 participants (15.45%) reported following the male agent more often, whereas five (4.55%) participants reported following the woman more often.