It is written in the eyes:

Inferences from pupil size and gaze orientation shape interpersonal liking

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RUNNING HEAD: Pupils-gaze interplay

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Abstract

Research has shown that pupil size shapes interpersonal impressions: Individuals with dilated pupils tend to be perceived more positively than those with constricted pupils. Untested so far is the role of cognitive processes in shaping the effects of pupil size. Two pre-registered studies investigated whether the effect of pupil size is qualified by partner's attention allocation inferred from gaze orientation. In Experiment 1 (N=50) partners with dilated pupils were more liked when gazing toward the participant, but less liked when gazing toward a disliked other. Experiment 2 (N=50) unveiled the underlying mechanism of the pupil-gaze interplay. Pupillary changes led to inferences about the feelings held by the partner towards the gazed target: larger the pupils signaled positive feelings. Crucially, target identity moderated the response of the participants (i.e., liking toward the partner). This work shows the importance of considering the interplay of affective and cognitive eye-signals when studying person perception.

Keywords: person perception, pupil size, eye-gaze, feelings, social interaction

In the absence of other relevant information, humans use facial features to make attributions about others. Inferences derived from someone's face are socially impactful and influence our judgements in short fractions of time (Freeman & Johnson, 2016; Rule et al., 2015; Todorov, Pakrashi, & Oosterhof, 2009; Todorov & Uleman, 2003). Among the many facial cues that drive interpersonal impressions, the human eye region stands out as particularly salient and powerful. Indeed, both infants and adults focus on their interaction partner's eyes, grasp emotion signals (Farroni, Csibra, Simion, & Johnson, 2002) and follow gaze (e.g., Macrae, Hood, Milne, Rowe, & Mason, 2002). In particular, two features of the human eye convey important information. Pupil size is thought to reflect inner affective states of an individual (Bradshaw, 1967). Gaze orientation, on the other hand, is among the prime signals for a partner's allocation of attention (Emery, 2000). Even if both pupil size and gaze orientation are key in shaping social impressions, how these two signals interact in predicting person perception is poorly understood. Here, we examine the interplay between pupil size and gaze orientation on impressions of partners within the context of a simulated social interaction. In particular, we test the possibility that pupil size predicts interpersonal liking and that this effect is qualified by partner's attention allocation inferred from gaze orientation.

A good deal of work has shown that pupil size is a cue that influences our perception of other individuals (Beatty & Kahneman, 1966; Hess, 1975; Laeng et al., 2012). As such, research evidence shows that partners with larger pupils are perceived as positive and beautiful, while those with small pupils, cold and distant (Hess, 1975; Kret & De Dreu, 2017; Kret, Fischer, & De Dreu, 2015; Kret, 2015). Moreover, the impact of pupil size can determine approach/avoidance behavioural reactions (Brambilla, Biella, & Kret, 2019). Importantly, the link between pupil size and positive traits is meant to be driven by the emotions revealed by pupillary change, meaning that from larger (vs. smaller) pupils the observer infers positive (vs. negative) emotions (Hess, 1975). Corroborating this hypothesis, recent research has shown that humans develop the ability to relate pupil size to specific emotional states, with larger pupils associated with positive emotions (e.g., happiness) and smaller pupils associated with negative emotions (e.g., anger, Kret, 2018). However, variations in one's pupil size can depend on a number of cognitive and emotional processes. Indeed, pupils dilate in response to high cognitive elaboration (Kahneman & Beatty, 1966), or arousal (Bradley, Miccoli, Escrig, & Lang, 2008; Hess & Polt, 1960; Kret, Roelofs, Stekelenburg, & de Gelder, 2013; Kret, Stekelenburg, Roelofs, & de Gelder, 2013). As pupil size can change in response to distinct processes, perceivers' interpretation of another person's pupillary change can vary as well. Because human responses to pupil size variation are determined by the meaning ascribed to such a variation, it would be key to understand the specific conditions within which perceived dilated vs. constricted pupils influence interpersonal liking.

Recent studies have highlighted that contextual factors influence how information conveyed by pupils is perceived and interpreted. For instance, within the context of a trust game, participants trusted partners with dilated pupils more, but only when they were ingroup members (Kret et al., 2015). In a similar vein, Pawling, Kirkham, Tipper, and Over (2017) showed that the impact of pupil size on attributed friendliness and interest was modulated by partner's gender and facial trustworthiness. These prior studies looked at the interplay between pupil size and static (dispositional or physical) features of the interacting partner. Such static features are likely to modulate the impact of pupil size on the relevant outcome by altering the baseline evaluation of the partner (e.g., trustworthy individuals tend to be more positive than untrustworthy individuals). Instead, no studies have investigated the role of dynamic facial cues in complementing the information conveyed by pupil size. Indeed, the human eye is a rich source of information that reveals emotional states through the pupils and the target of such internal states via eye gaze. Whereas pupillary change signals the emotions experienced by an interacting partner, gaze-orientation is crucial to understand the target to whom such emotions are actually addressed. Reliance on eye-gaze perception to interpret social behaviour is a central facet of social interactions that starts from infanthood and develops through all the subsequent stages of our life (see Emery, 2000; Frischen, Bayliss, & Tipper, 2007, for reviews). In fact, through others' gaze we gain information regarding the target of an observed emotional reaction and such information modulates our response (Mojzisch et al., 2006; Shilbach et al. 2006). For instance, the impact of emotions inferred from facial cues is modulated by the extent to which the observer feels (s)he is the target of those emotions (Grèzes et al., 2013; Schrammel, Pannasch, Graupner, Mojzisch, & Velichkovsky, 2009; Soussignan et al., 2013).

Notwithstanding the fact that both cues are gathered from the eye region, the interplay between pupil size and gaze orientation has been largely ignored. To the best of our knowledge, only one prior study has explored the simultaneous impact of partner gaze orientation and pupil size (Van Breen, De Dreu, & Kret, 2018). In that study, the authors considered both the unique and joint effects of dilating pupils and eye-gaze on prosocial behaviour and found that participants were less likely to behave dishonestly when (i) the pupils of their partner dilated and (ii) the gaze of the partner was oriented to them, but no interaction between gaze orientation and pupils size emerged. Critically however, the extent to which partner eye-gaze is integrated into the information retrieved from pupil size can vary dramatically depending on the context within which the two factors are manipulated. Here, we propose that social interaction involving multiple actors might represent a fertile ground for eye-gaze to complement the affective information conveyed by the pupil size. For instance, imagine a typical everyday situation where two strangers, Bob and Ann, randomly meet on the bus while wearing facial masks. Bob notices that Ann is looking in his direction and that her pupils are dilating. The contingency of these two events somehow pleases Bob, who is about to respond to Ann with a friendly smile. All of a sudden, Bob realizes that Ann’s gaze is not oriented toward him, but instead toward an old friend of her who happens to be sitting just behind Bob. Sadly, Bob has no longer reasons to smile at Ann. This real-life scenario offers a clear example of how pupil size and eye-gaze can complement each other by providing affective information (i.e., pupil size) and specifying the target of that affective information (i.e., eye-gaze).

Our work aims at extending prior insights by testing the joint effect of pupil size and gaze orientation in shaping interpersonal perception. Specifically, in two pre-registered studies we induced a simulated interaction and tested the effect of partner pupillary change on interpersonal liking when the eyes of the partner gazed either towards the participant or an imagined other. Based on the assumption that pupillary change is used as a signal to infer other's emotional states, the aim of our investigation is twofold. First, we tested whether the effect of pupil size on interpersonal liking is influenced by contextually relevant information that informs the perceiver about the target of partner pupil size variation. Namely, we manipulated the identity of the attentional target and tested how this factor moderated the pupil size effect. Second, we focused more directly on how information gathered from both pupillary change and gaze target can complement each other. On the one hand, gaze target can alter the meaning of pupillary changes (i.e., difference in inferred feelings based on gaze orientation). Alternatively, it might modulate the relationship between the nature of such feelings and the ultimate response of the perceiver (i.e., greater liking when pupil dilation is addressed towards a positive, but not a negative, target).

Moreover, studying the impact of attentional cues to complement the information conveyed by pupil size sheds light on the processes through which pupil size is meant to influence interpersonal liking. Prior research has suggested that inferring emotions from the eye region is triggered automatically and unconsciously in a bottom–up fashion (Sadrô, Jarudi, & Sinha, 2003; Leppänen, Hietanen, Koskinen, 2008). However, saying that inferences about specific emotional states activates spontaneously when a facial cue is processed does not imply that the response of the perceiver to that cue is automatic, or unaffected by contextual factors. Here, we propose a functional interpretation of the pupil size effect. In functional terms, the critical response to partner pupillary change (i.e., overall liking) is the consequence of specific regularities in the environment (see De Houwer, Barnes-Holmes, & Moors, 2013). Importantly, some regularities are acquired in past environments, while some other are directly available at the moment behaviour changes. Here, we propose that via regularities acquired in past (social interaction) environments, participants should come-up with a common interpretation of partner pupil size variation. Instead, partner gaze orientation should operate as the factor in the present environment that complements pupil size variation to ultimately qualify the response of the perceiver.

Experiment 1

Experiment 1 tested whether the effect of pupil size on interpersonal liking is conditional upon partner gaze target, that is, either the participant or an idiosyncratically disliked person. We predicted that when the eyes of a partner are oriented towards the participant, the expected positive feelings inferred from pupil dilation leads to positive liking judgments. Instead, when the target is a disliked other, the very same dilated pupils might speak for partner positive feelings towards a person that the observer dislikes and therefore elicit less attribution of positive traits. In manipulating both pupil size and gazed target, we also presented participants with verbal instructions to anticipate the perceptual variations at the level of the eye region of the partner. These instructions aimed to neutralize any discrepancies in terms of attention due to partner's gaze orientation. In fact, prior research on gaze orientation showed that seeing a face with direct (vs. shifted) gaze engages the observer's attention (see Frischen et al., 2007; Baron-Cohen, 1995). Nonetheless, the inclusion of instructions represents an important element of novelty within this specific field of research. In fact, as prior studies found an effect of pupil size without perceivers being capable to verbalize such variation when directly asked, the impact of pupil size is often treated as something that occurs outside of conscious awareness. This is the first empirical contribution to test the effect of pupillary changes under conditions of awareness.

Method

The study employed a 2 × 2 within-subjects design, in which pupil size of the interaction partner (dilating vs. constricting) and the gaze target (self vs. disliked other) were the factors. Interpersonal liking was measured via three items (i.e., attribution of attractiveness, friendliness and trustworthiness to the partner). For both experiments, we reported all the manipulations and measures administered in the experimental procedures. The studies were pre-registered on Open Science Framework (https://osf.io/p3vym/?view_only=14e474f51e9e4879b676bba3125e8d5f).

Experimental materials, data, and analysis code are available at https://osf.io/etz8s/?view_only=53e6d3b4d71d4133bc470fe3adfeeebf.

Power analysis

As preregistered, the samples of the two studies were based on power analyses conducted in G Power. The projected sample size needed to detect a medium effect size $d = .50$, with power of .80 ($\alpha = .05$) was N = 34 for a 2 x 2 within subject ANOVA (Experiment 1) and N = 46 for a 2 x 3 within subject ANOVA (Experiment 2). In both experiments, we opted for a larger sample size comparable to previous studies investigating the impact of pupils on social perception (e.g., Brambilla, Biella, & Kret, 2019; Kret & De Dreu, 2019).[1]

Participants and procedure

Both experiments were approved by the Ethics Committee of the University of Milano-Bicocca. Fifty participants (39 females, $M_{age} = 22.24$, $SD_{age} = 3.91$) took part in experiment 1. Upon arrival to the laboratory, participants provided informed consent to participate in the research. Participants were then invited to seat on a chair located in front of a computer screen. The screen was located 55 cm far from the participants. During the experimental session, an additional chair was located near and slightly behind (80cm left, 15cm behind) the participant. In the first part of the experiment, participants underwent an induction phase in which they were asked to think about a personally relevant disliked other and to imagine that person sitting on the chair located next to them. Participants were then introduced to a virtual social interaction scenario in which different

[1] We acknowledge that the power analyses performed before running the two studies suffer from two main limitations: First, they were not based on the generalized mixed models approach used in the studies. Second, they were performed using G Power, which has proven as not fully reliable for within-subject designs. To prove that the two studies were both highly powered, we conducted two sensitivity analyses. Rather than using the actual effect size of the study, a safeguard approach (Perugini, Gallucci, & Costantini, 2014) was chosen. Thus, we first calculated the 95% CI of the critical (interaction) effect. Then, we used "simr", an R package designed for sensitivity analyses with mixed models design, to estimate the power of the two studies using the 95% CI lower bounds in place of the observed effects. This allowed us to estimate the power of the two studies to detect a real interaction effect given an effect size that 95% of the times was lower than the actual effect. In Experiment 1, the estimated (non-standardized) interaction term was 1.86 (lower bound was 1.69). In Experiment 2, the interaction was 1.12 (lower bound was .96) when considering self vs. disliked-other trials, and 1.28 (lower bound was 1.12) when considering liked other vs. disliked other trials. After replacing the observed effects with the relevant lower bound, testing 50 participants yielded over 99% power to detect an interaction effect in both the experiments. As an additional remark, we found that a reduction in effect size of 35% (i.e., Experiment 1: 1.20; Experiment 2: 0.73 and 0.83) would still yield over 99% power to detect the interaction.

partners of interaction were presented on screen in sequence. Both pupil size (constricted vs. dilated) and the target gazed by the partners of interaction (self vs. disliked other) varied across trials. Participants were instructed to use the information conveyed by the eye region of each partner to form an impression about them. Right after the exposure to each video, participants rated the target partner on three dimensions (e.g., attractiveness, friendliness and trustworthiness, Kret & De Dreu, 2019). After that, participants answered two exploratory questions testing the extent to which they believed the virtual partners were actually gazing at the supposed target across the two gaze conditions, and their level of awareness of partner pupillary variation in size across the two gaze conditions. Participants answered both the believability and the awareness question on a 7-point scale, ranging from 1 (not at all) to 7 (completely).[2] Next, they completed demographics, were thanked, debriefed and given course credits.

Stimuli

To create virtual partners, we selected pictures of four men and four women of Western European descent with a neutral expression from the Amsterdam Dynamic Facial Expression Set (ADFES; van der Schalk, Hawk, Fischer, & Doosje, 2011). Pictures were standardized in Adobe Photoshop, converted to gray scale, and cropped to reveal only the eye region. Cropping to reveal just the eye region threatens ecological validity, but enables improved measurement (Kret, Tomonaga, & Matsuzawa, 2014). After cropping each stimulus, we erased everything between the eyelashes. Next, the average luminance and contrast were calculated for each picture, and each picture was adjusted to the mean. The eyes were then filled with new eye whites and irises, and an artificial pupil was added in Adobe After Effects. The intermediate shade of the iris, used in all new pictures, was taken from the shade of one iris pair. To emphasize the convex shape of the eye and increase naturalness, we made the eye white around the iris brighter than the eye white in the outer edges of the eye. Pupil dilations and constrictions occurred within the physiological range of 3 to 7

[2] Both believability (self: $M = 5.98$, $SD = 1.36$; disliked other: $M = 5.40$, $SD = 1.59$) and awareness of pupillary change (self: $M = 6.14$, $SD = .83$; disliked other: $M = 5.98$, $SD = 1.02$) were high (above the midpoint of the scale) in both conditions and we did not analyse them further.

mm (always from 5 to 7 mm, from 5 to 3 mm, or from 5 to 5 mm). To increase ecological validity, we added a slightly trembling corneal reflection, and although the pupil dilation or constriction was linear, the edges were rounded off with an exponential function (natural formula implemented in After Effects) to smooth the change. We based the time course of partner's pupil change on actual pupil responses from participants in a previous study (Kret et al., 2014), and thus the maximum or minimum of partners' pupil change was achieved after 3000 ms, after which the pupils remained static for another 1000 ms. This duration is consistent with the facial-mimicry literature, in which electromyographic responses are most commonly measured over 4000 ms (Kret et al, 2013; Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001). Moreover, the position of the iris and pupil of the partner was either in the middle of the eye (participant-oriented) or shifted to the left (disliked other-oriented). For each stimulus identity there were 4 videos, one for each condition obtained from the two key factors (pupil size and gaze orientation). Thus, there are 32 unique videos, each repeated twice, leading to a total of 64 videos.

Materials

Induction phase. Participants were instructed to think about a disliked person. An initial screen asked participants to recall a specific unpleasant life-event involving that person and to describe it briefly in blank text box. In the following screen, participants provided the first name and the initial of the family name of the disliked person in two blank boxes. Next, they were asked to imagine that the disliked person was actually seated on the chair located next to them and that (s)he would be part of the next task.

Virtual social interaction task. Participants were presented with two consecutive blocks of 32 trials each. In the first stage of each block, they saw the eye region of the partner. Depending on the type of trial, the gaze of the partner's eyes could be oriented towards either the participants or the disliked other. Also, the pupils of the partner's eyes could dilate or constrict. The onset of a message asking participants to evaluate the partner signalled that the video is over. Participants evaluated each person on attractiveness *("How much do you like this person?")*, friendliness *("How* *friendly is this person?"*) and trustworthiness *("How much do you trust this person?")* on a 7-point scale (1=not at all; 7=Very much). The order of presentation of the three questions was randomized.

Statistical analysis

Data were analysed in a two-level generalized mixed model. The 64 trials were nested within participants. Partner pupil size (dilating or constricting), gaze orientation (self or disliked other) and their interaction were included as fixed factors and both the individual and the stimuli identity intercepts as a random factors. This analytical approach has the advantage to account for intraindividual variance and to allow for the inclusion of a random intercept. The model-procedure always started with a full model that includes all fixed factors, including interactions. After specifying the fixed effects, model building proceeded with statistical tests of the variances of the random effects. In case of significant interaction between pupil size and gaze orientation, we conducted follow-up *t*-test to inspect the impact of pupillary change on either gaze orientation condition. Because the correlations between the three attributed traits (i.e., attractiveness, friendliness and trustworthiness) was high (*r*s > .77, *p*s < .001) we collapsed them to obtain a unique indicator of overall liking and included it as outcome in our analyses (see Supplementary Materials for the analyses on the three outcomes).

Results

A main effect of pupil size showed that participants liked partners with dilating pupils more than those with constricting pupils, $\beta = .68$, $F(1, 3138) = 59.19$, $p < .001$. A main effect of gaze target also emerged, $\beta = .61$, $F(1, 3138) = 35.02$, $p < .001$, with higher liking towards partners gazing toward the participant than the disliked-other. Crucially, the interaction between pupil size and gaze target was significant, $\beta = 1.86$, $F(1, 3138) = 496.21$, $p < .001$. Follow-up *t*-tests showed that dilated pupils led to higher general liking than constricted pupils when the eyes of the partner were oriented towards the participant (dilated: $M = 4.13$, $SD = 1.46$; constricted: $M = 2.88$, $SD = 1.32$), $t(1541.01) = 21.38$, $p < .001$. Instead, when the eyes of the partner were oriented towards the disliked other, dilated pupils lead to significantly lower attribution of liking than constricted pupils (dilated: $M = 2.96$, $SD = 1.29$; constricted: $M = 3.56$, $SD = 1.38$), $t(1541.01) = -10.80$, $p < .001$ (see Figure 1). Thus, Experiment 1 suggests that the effect of pupil size on liking can be moderated by the target of a partner's gaze.

Experiment 2

Having shown that pupillary change impacts upon liking differently based on partner gaze orientation, we turned our attention to the explanatory mechanism of the observed interplay. First, we added one level to our gaze target manipulation: partner gaze could be oriented towards either the participant, a disliked other or a liked other. This was done to test whether the interaction observed in Experiment 1 was driven by target-valence, or whether other competing factors could have played any role. For instance, the effect of pupil size on liking has been interpreted in terms of mimicry (Prochazkova & Kret, 2017): by mimicking what expressed by a partner eyes, the perceiver synchronizes with the emotional states cued by pupils and this should eventually affect the perception of the partner. As direct eye-contact fosters mimicry (Wang, Newport, & Hamilton, 2011) one could argue that the variation on the pupil size effect based on gaze target observed in Experiment 1 is merely driven by mimicry. Crucially, mimicry and target-valence lead to divergent predictions in Experiment 2. Mimicry should predict the effect of pupil size to be stronger when the eyes of the partner are oriented towards the participant (as opposed to both the liked and the disliked other). Conversely, a target-valence explanation would predict a superior impact of pupil size on liking when the partner gazes the liked other, as opposed to the disliked other. Second, rather than merely assuming that the impact of pupil size on liking is mediated by the nature of the emotional state that the perceiver infers from pupils, Experiment 2 tested this mediation. After judging the interacting partners, participants were asked to infer the nature of the feelings experienced by the partner towards the gazed target. Larger partner pupils should lead participants to infer more positive feelings on the part of the partner towards the gazed target. However, we expected the identity of the gazed target of such feelings to modulate the impression of the partner:

positive feelings towards either the participant or the liked other should lead to greater liking, whilst positive feelings towards the disliked other should not affect liking (or lead to reversal).

Method

We adopted a 2 × 3 within-subjects design, with pupil size of the interaction partner (dilating vs. constricting) and the gaze target of the interaction partner (self vs. disliked other vs. liked other) as factors.

Participants and Procedure

Fifty participants (42 females, M_{age} = 22.80, SD_{age} = 5.01) were recruited to participate. The entire procedure mirrored that used in Experiment 1, except for the virtual inclusion of the liked other in the interaction context and the additional question to measure inferred feelings. Therefore, the same induction procedure used in Experiment 1 was repeated twice to make participants think about a liked person first, and to a disliked person next. Two empty chairs were located next to the participants seats, one on the left and the other one on the right. Next, instructions introduced participants to a social interaction context, identical to that of Experiment 1, except for the fact that partner's gaze could be oriented towards the participants, the liked other or the disliked other. Assignment of the two targets to either location was counterbalanced across participants. Participants evaluated each partner on attractiveness, friendliness and trustworthiness. An additional question measured participants inferences about the feelings experienced by the partner towards the gazed target (either the participant, the liked other, or the disliked other, depending on the gaze condition). The following question was then administered after the three traits attribution questions: "What feelings do you think this person experienced towards [gaze target]?). Responses to this question were provided on a 7-point scale (1=very negative; 7=very positive). Manipulation of the eight partner's identity on both pupil size and gaze orientation led to 48 videos, repeated across two separate blocks.[3]

[3] The same believability and awareness questions were included. Believability scores were high and above the midpoint of the scale for the three gaze conditions (self: M = 6.28, SD = 1.03; liked other: M = 6.10, SD = 1.07; disliked other: M = 5.94, SD = 1.35). Awareness of pupillary change showed also high and above the

Statistical analysis

First, we investigated the impact of pupil size and gaze orientation on overall liking, obtained after averaging the same outcomes used in Experiment 1 (rs > .80, ps < .001). We tested the main effect of pupil size and gaze target, as well as their interaction, on both overall liking and inferred feelings. Then, we conducted a moderated-mediation analysis to test (i) whether the impact of pupil size on overall liking is explained by inferred feelings, and (ii) whether this whole effect was moderated by partner gaze target. All the regression paths were estimated by including the main effect of pupil size and gaze target, as well as their interaction as fixed factors, and both the individual and the stimuli identity intercepts as random factors.

Results

Overall Liking. We found a main effect of pupil size in the expected direction, $\beta = .86$, $F(1, 4738) = 655.06$, $p < .001$, such that dilated pupils led to greater attribution of liking than constricted pupils. Gaze orientation was also significant, $F(2, 4738) = 8.13$, $p < .001$, indicating lower liking for partners looking at the disliked other compared to both partners looking at the self or at the liked other, $\beta = .12$, $t = 2.76$, $p = .006$ and $\beta = .16$, $t = 3.66$, $p < .001$. There was no difference when comparing participant-oriented and liked other-oriented gaze, $\beta = .04$, $t = 0.79$, $p = .427$. The interaction term was significant, $F(2, 4738) = 144.05$, $p < .001$. This interaction was significant when comparing the disliked other with the self, $\beta = 1.12$, $t = 13.67$, $p < .001$, and the disliked other with the liked other, $\beta = 1.28$, $t = 16.03$, $p < .001$. Follow-up t-tests showed that dilated pupils led to higher attribution of general liking than constricted pupils when the eyes of the partner were oriented towards the participant (dilated: $M = 4.11$, $SD = 1.43$; constricted: $M = 2.93$, $SD = 1.27$), $\beta = 1.27$, $t(1542) = 19.50$, $p < .001$, and towards the liked-other (dilated: $M = 4.23$, $SD = 1.33$; constricted: $M = 2.89$, $SD = 1.23$), $t(1542) = 23.21$, $p < .001$. The effect of pupil size was not

midpoint of the scale across all conditions (self: M = 6.12, SD = .96; liked other: M = 6.28, SD = .80; disliked other: M = 5.98, SD = 1.06).

detectable when the eyes of the partner were oriented towards the disliked other (dilated: $M = 3.43$, $SD = 1.25$; constricted: $M = 3.37$, $SD = 1.17$), $t(1542) = 1.09$, $p = .277$ (see Figure 2).[4]

Inferred feelings. We found a main effect of pupil size, β = 1.85, $F(1, 4738) = 2205.41$, $p < .001$, indicating that larger pupils induced inferences of more positive attitudes experienced by the partner towards the gazed target. We also found a significant effect of gaze, $F(2, 4738) = 19.99$, $p < .001$, indicating more positive feelings attributed to partners looking at the self as compared to the disliked other, β = .26, $t = 4.61$, $p < .001$, and to partners looking at the liked other as compared to the disliked other, β = .26, $t = 4.44$, $p < .001$, but no significant difference between the liked and the disliked other conditions, β = .001, $t = .01$, $p = .991$. The interaction term was significant, $F(2, 4738) = 7.72$, $p < .001$. This interaction was significant when comparing the liked other with both the disliked other and the self, β = .34, $t = 3.48$, $p = .001$ and β = .32, $t = 3.40$, $p = .001$, but not when comparing the self and the disliked other, β = .02, $t = .16$, $p = .877$. Follow-up *t*-tests showed that increased pupil size led to inference of more positive feelings when the eyes of the partner gazed the liked other, $t(1542) = 30.64$, $p < .001$, as compared to when the participant or the disliked other were the target, $t(1542) = 26.59$, $p < .001$ and $t(1542) = 25.74$, $p < .001$, respectively.

Moderated-mediation analyses. We did not report the regressions that tested *path c* and *path a* (i.e., impact of pupil size and gaze target on overall liking and inferred feelings, respectively) as they are just a formal replication of what presented in the previous sections. Crucial to test our hypothesis was *path b*, in which we included pupil size, inferred feelings, gaze target, and the interaction between gaze target and the other two variables as predictors of overall liking. We found a significant effect of feelings, $b = .40$, 95% CI [.38, .42], $p < .001$, a significant, although reduced, effect of pupil size, $b = .08$, 95% CI [.01, .15], $p = .017$, and a non-significant effect of gaze, $b = .04$, 95% CI [.004, .07], $p = .027$. More importantly, we found no significant interaction between pupil size and gaze target, $b = .03$, 95% CI [-.05, .12], $p = .423$, but a significant interaction

[4] We checked for the impact of the location in which the (dis)liked other was supposed to be seated. We found no effect on overall liking, $F(1, 48) = .08$, $p = .770$.

between inferred feelings and gaze target, *b* = .28, 95% CI [.26, .31], *p* < .001. The latter interaction proved the moderated-mediation, and also clarified that gaze target qualifies the impact of pupil size on liking by modulating participants' response to the feelings inferred from partner pupil size. We inspected the moderated-mediation by testing three simple mediations on the three gaze target condition (see Figure 3). When the eyes of the partner gazed the self, we found a significant total effect of pupil size on liking, *b* = 1.18, 95% CI [1.06, 1.30], *p* < .001. There was a significant effect of pupil size on inferred feelings, *b* = 1.75, 95% CI [1.62, 1.88], *p* < .001, and a significant effect of feelings on liking, *b* = .64, 95% CI [.61, .68], *p* < .001. The indirect effect was significant, *b* = 1.12, 95% CI [1.03, 1.22], z = 18.23, *p* < .001. Instead, the direct effect showed that the impact of pupil size on liking was no longer significant after inclusion of inferred feelings, *b* = .05, 95% CI [-.05, .16], *p* = .300. The same analysis was run on liked other-oriented trials. The total effect of pupil size on liking was significant, *b* = 1.34, 95% CI [1.22, 1.45], *p* < .001. The effect of pupil size on inferred feelings was significant, *b* = 2.07, 95% CI [1.94, 2.21], *p* < .001, and so was the effect of feelings on liking, *b* = .60, 95% CI [.57, .63], *p* < .001. Similar to what found on participant-oriented trials, the Sobel test indicated a significant indirect effect, *b* = 1.24, 95% CI [1.14, 1.34], z = 20.27, *p* < .001. Also in line with what observed on participant-oriented trials, we found that the direct effect was no longer significant after the inclusion of the effect of inferred feelings, *b* = .10, 95% CI [-.003, .20], *p* = .057. Last, we focused on disliked other-oriented trials. There was no total effect of pupil size on liking, *b* = .06, 95% CI [-.05, .16], *p* = .277, a significant effect on inferred feelings, *b* = 1.74, 95% CI [1.60, 1.87], *p* < .001, and no effect of feelings on liking, *b* = -.001, 95% CI [-.04, .04], *p* = .966. Thus, the indirect effect was not significant, *b* = -.001, 95% CI [-.08, .09], z = -.03, *p* = .977. The direct effect was also not significant, *b* = .06, 95% CI [-.07, .18], *p* = .349.

Experiment 2 replicated the interaction between gaze target and pupil size on liking. Differently from Experiment 1, we did not find a reversal of pupil size when the eyes of the partner were oriented towards the disliked other, but instead, a null effect. Yet, the significant interaction between pupil size and gazed target proved that the latter is key to determine how individuals respond to partner pupil size variation in social interaction contexts. In fact, we showed that the nature of the gazed target was key to determine whether the feelings inferred from partner pupil size eventually induced greater liking. Whereas pupil size led to a comparable effect on inferred feelings across each gaze orientation condition, whether or not such inferences about partner's feelings resulted in greater liking depended on partner's gaze orientation.[5]

General discussion

In social contexts, humans gather relevant information through the eyes of their partner of interaction (Kobayashi & Kohshima, 1997). Two specific features of the eyes, namely pupil size and gaze orientation, inform us about partner affective states, and allocation of attention, respectively (Bradshaw, 1967; Tomasello, Hare, Lehmann, & Call, 2007). This work represents the first attempt to study the joint impact of pupil size and gaze orientation in shaping interpersonal liking within a context of (simulated) non-dyadic interaction. Starting from the classic pupil size effect on attribution of positive traits (e.g., Hess, 1975), we focused on the moderating role played by partner eye-gaze. Across two experiments, participants integrated the emotional information derived from pupil size with attentional information derived from partner gaze. Therefore, based on the nature of the gazed target, pupillary changes led to contrasting responses in terms of interpersonal liking: whereas partners with dilated pupils were more liked when gazing towards either the participant or a liked individual, this was not the case when dilated pupils were oriented towards a disliked individual. In particular, in the latter condition we found a reversal in the pupil size effect in Experiment 1, and a null effect (i.e., no difference between dilating vs. constricting pupils on liking) in Experiment 2. Although any interpretation of such a discrepancy would be rather speculative at this stage, we advance the hypothesis that whereas in the condition where pupils vary in response to a liked target the response of the perceiver is rather univocal (i.e., dilated

[5] A third experiment was planned to replicate the same pattern of results in a social interaction context involving the participant and the disliked other only (like in Experiment 1). Unfortunately, we could not collect fifty participants as planned due to the COVID-19 contingent situation. For the sake of transparency, we reported the results of Experiment 3 (N=19) in the Supplementary Materials. Importantly, even with a small sample the pattern of results replicated those reported in Experiment 2.

pupils lead to greater liking than constricted pupils), greater heterogeneity might rise when the target is a negative one. Future studies might explore further what factors might induce either one or the other response to pupil dilating (vs. constricting) towards a negative target perhaps manipulating the characteristics of the dislike other (e.g., peer vs. distal family member vs. colleagues).

The positive relation between pupil size and interpersonal liking is well-documented in literature. Partners with larger pupils are perceived as more attractive (Demos, Kelley, Ryan, Davis, & Whalen, 2008), more trustworthy (Kret & De Dreu, 2017) and are more approached than those with constricted pupils (Brambilla et al., 2019). Although such an effect is often depicted as inevitable, prior studies offered ancillary evidence that contextual factors may modulate it (Pawling et al., 2017; Kret et al., 2015). However, in such prior studies the contextual factors manipulated were static features of the partner (e.g., group membership, gender and facial trustworthiness). By altering the baseline evaluation of an interacting partner, static features might either alter the extent to which the perceiver is inclined to modulate their impression of the partner based on pupillary change. Or, they can affect the meaning attributed to pupillary change: for instance, pupil dilation in untrustworthy individuals might cue high negative arousal, whereas pupil dilation in trustworthy individuals cue positive feelings. Our work is the first to show that a dynamic cue, that is, partner eye-gaze, can also alter the effect of pupil size on liking. Differently from other (static) features, partner eye-gaze does not qualify the partner. Rather, within a context of simulated social interaction, eye-gaze is functional to complement the information derived from pupil size variation by informing about the target of such a variation. In other words, eye-gaze complements what cued by pupil size, qualifies its meaning and eventually influences individuals' response to it.

Beside highlighting an important boundary of the pupil size effect (i.e., eye-gaze), our findings have implications from a theoretical perspective. One interpretation of the impact of pupil size is based on the idea that, during eye-contact, the pupil size of the observed tend to synchronize with that of the partner (Harrison, Singer, Rotshtein, Dolan, & Critchley, 2006). By mimicking the behavioural reaction expressed in a partner eyes, the emotional states of the perceiver should converge with those of the partner and this would eventually influence the perception of the partner (Prochazkova & Kret, 2017). However, in Experiment 2 we found a positive effect of partner pupil dilation on liking when the partner eyes gaze a liked other. Because no direct contact between the participants and the partners was established in liked other gaze condition, the mimicry interpretation is difficult to reconcile with the present findings. Because the role of pupil mimicry has been proposed as key to predict the impact of pupil size on interpersonal liking, it would be interesting to systematically investigate which contextual factors trigger (vs. suppress) pupil mimicry and the subsequent impact on liking. For instance, participants might be induced to believe that a disliked other is seated in between themselves and the partner of interaction (same latitude) and that partner pupil variation is emitted in response to either target. Under such condition, mimicry should predict no difference based on the gazed target, whereas target valence should predict a replication of the critical interaction.

In search for potential explanatory mechanisms for the effect of pupil size, we explored the role of inferred feelings. The idea of pupil size affecting liking via communicated affective states has been proposed since the earliest work by Hess (1975). However, no studies have ever empirically tested whether the impact of pupil size on liking is conditional upon the inferences that the perceiver makes about a partner's affective states. As evidenced by results from Experiment 2, we found that individuals used pupillary changes to infer how the partner felt about the gazed target: dilated partner pupils signalled positive feelings. Besides, we proved statistically that the impact of pupils on liking is fully mediated by inferred feelings, meaning that the effect of pupil size vanishes when the impact of the feelings inferred from pupils is partialed-out. Although we acknowledge that testing for one mediator does not rule out other countless explanatory variables (Fiedler, Schott, & Meiser, 2011), our results extend previous literature and showed that inferential reasoning is crucial in qualifying our reaction to pupillary changes. Moreover, the significant moderated-mediation indicated that feelings inferred from pupils are not just relevant to explain how pupils influence interpersonal liking. In fact, it is via determining the target of such feelings that partner gaze orientation moderates the impressions derived from pupil size.

This research is also novel in that it shows that pupil size can alter interpersonal liking when participants are fully aware of such variation. To neutralize any potential discrepancy in terms of attention due to partner's gaze orientation (see Frischen et al., 2007; Baron-Cohen, 1995), in both studies participants received verbal instructions intended to make sure that they noticed the change in pupil size across partner gaze condition. Responses to an awareness question indicated that participants were well aware of the pupil size variation in all the partner's gaze condition (at least at a deliberative level), therefore ruling-out any potential explanation of the effects in terms of attention. Our work adds to prior literature that showed that partner pupil size can affect interpersonal judgments without perceivers being aware of the critical variation in the eye of the interacting partner (Demos, Kelley, Ryan, Davis, & Whalen, 2008). We showed that pupil size influences liking judgments even when the perceiver is prepared to process such information and therefore fully aware of it. Importantly, in anticipating a perceptual variation, our instructions remained silent with respect to the meaning of pupillary change (i.e., the nature of the emotions that pupil size was meant to signal): the meaning ascribed to pupil dilation vs. constriction was entirely left to the perceiver. Thus, the perceiver noticed the variation in pupil size, spontaneously gave significance to such a variation (i.e., dilated pupils mean positive feelings), and ultimately responded to it depending on the nature of the gazed target. Because awareness is often treated as a key variable that speaks for the nature of the underlying mental process of an observed phenomenon, future studies should investigate more systematically the impact of awareness in qualifying the pupil size effect and its interaction with contextual factors such as gaze orientation.

In summary, this work sheds light on the impact of contextual factors in qualifying our response to perceived pupil size variation. Within a simulated social interaction context, we demonstrated that the effect of pupil size is explained by the inferences we make about a partner internal states primed by pupils: people use pupil dilation (vs. constriction) as a signal of positive (vs. negative) affective states. Moreover, we showed that crucial to determine our response to such inferred affective states is the target of our partner gaze: interacting partners were more liked when their pupils dilated in response to a positive target, not when the target was negative. On the hand, inferences triggered by pupil size about the affective states hold by the partner towards the target are consistent across partner gaze orientation. We stick to a functional level of analysis in saying that such an effect might reflect the impact of a long history of learning based on which the individual has acquired what pupil dilation means within this context. On the other hand, partner gaze orientation was the key contextual information that participants used to complement what acquired from pupil size and that ultimately determined their response in terms of liking. This research paves the way for future investigation interested in better understanding role of the eyes in social communication.

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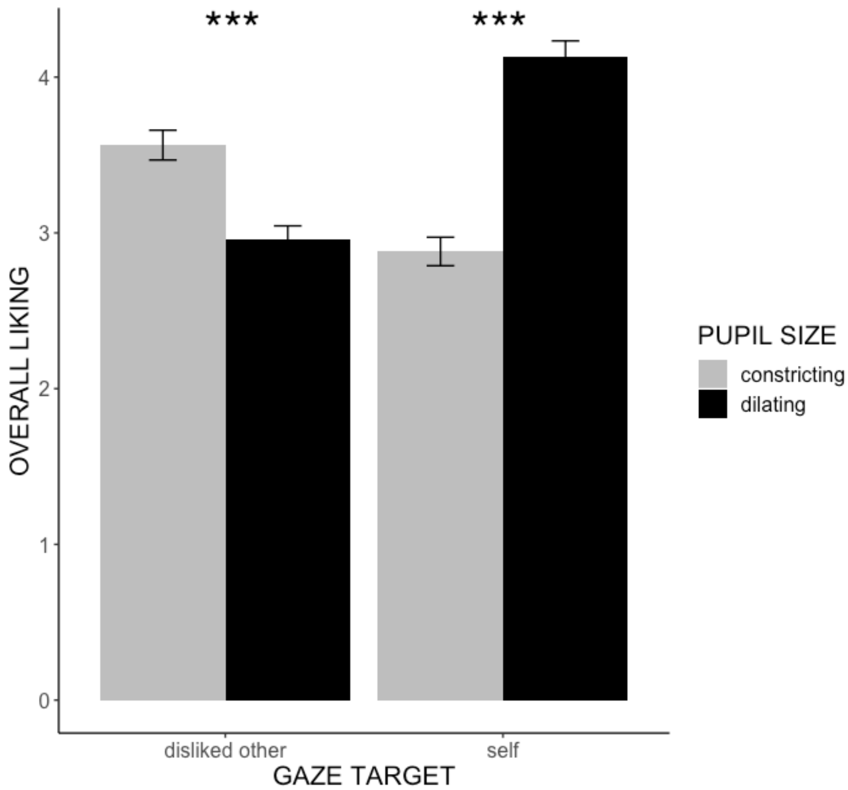

Figure 1. *Effect of pupil size and gaze orientation on overall liking (Experiment 1)*

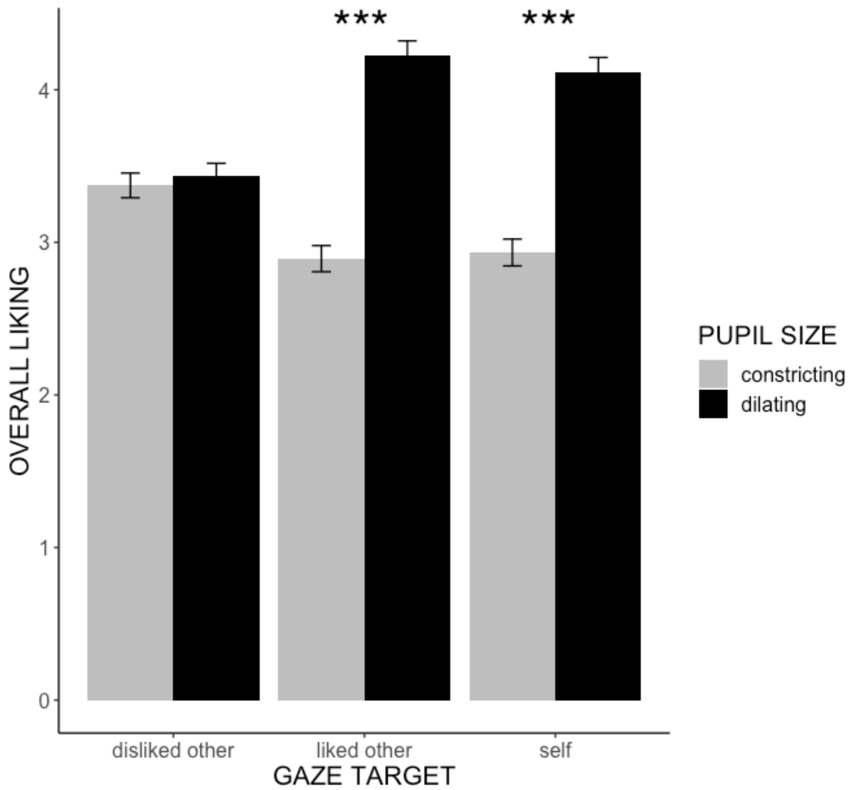

Figure 2. *Effect of pupil size and gaze orientation on overall liking (Experiment 2)*

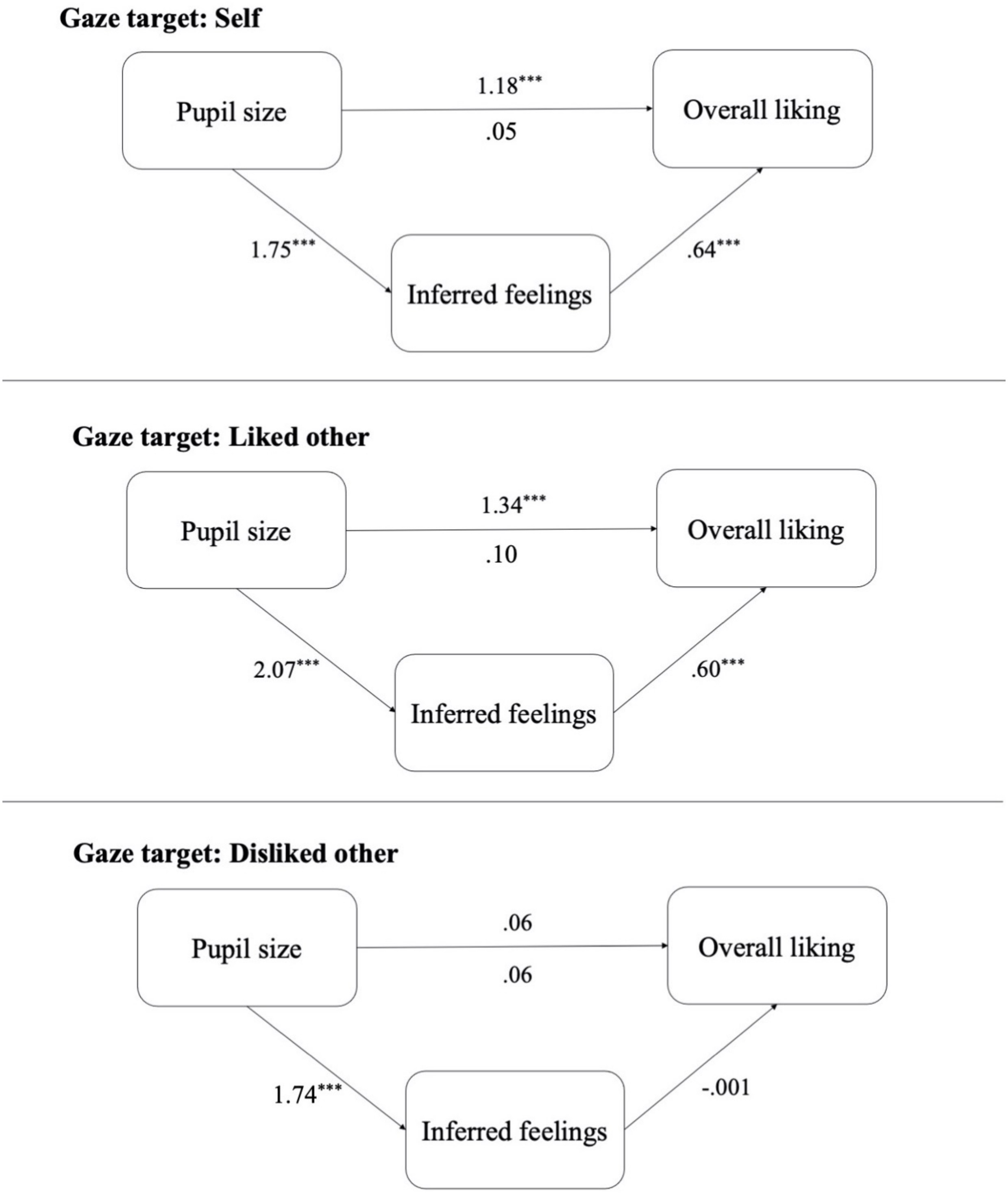

Figure 3. Mediation analyses that shous the impact of inferred feelings in explaining the effect of pupil size on liking across the three gaze target conditions (Experiment 2)

Supplementary Materials

Experiment 3

Method

We adopted the same 2 x 2 design used in Experiment 1, with both pupil size and gaze target varying across two levels.

Participants and Procedure

Although we originally planned to collect a total of fifty participants to be consistent with prior studies, data collection for this experiment is reduced due to the contingent COVID-19 situation. A total of nineteen university students (13 females, $M_{age} = 26.58$, $SD_{age} = 4.76$) participated in the study. The entire procedure mirrored that used in Experiment 1, except for the inclusion of the inferred feelings question and the very end of each of the 64 trials.

Statistical analysis

Following the same strategy adopted in Experiment 2, we first tested the main effect of pupil size and gaze target, and their interaction, on the single measure of overall liking (correlations between the three traits measures was high: rs > .67, ps < .001) as well as on inferred feelings. Then we focused on the moderated-mediation analysis, mirroring the same logic applied in Experiment 2.

Results

Overall liking. Participant liked partners with dilating pupils more than those with constricting pupils, $\beta = .36$, $F(1, 1187) = 40.50$, $p < .001$. We did not find a main effect of partner gaze target, $\beta = .01$, $F(1, 1187) = .02$, $p = .877$. The interaction term was significant, $\beta = .73$, $F(1, 1187) = 42.24$, $p < .001$. Follow-up t-tests showed that dilated pupils led to higher general liking than constricted pupils when the eyes of the partner were oriented towards the participant (dilated: $M = 4.02$, $SD = 1.28$; constricted: $M = 3.29$, $SD = 1.24$), $t(581) = 8.95$, $p < .001$. Instead, the effect of pupil size was no longer significant when the eyes of the partner were oriented towards the disliked other (dilated: $M = 3.66$, $SD = 1.06$; constricted: $M = 3.67$, $SD = 1.17$), $t(581) = -.10$, $p = .919$).

Inferred feelings. We found a main effect of pupil size, $\beta = 1.04$, $F(1, 1187) = 211.94$, $p < .001$, which indicated that larger pupils induced inference of more positive feelings experienced by the partner towards the gazed target, as compared to constricted pupils. A significant effect of gaze, $\beta = .23$, $F(1, 1187) = 9.92$, $p = .002$, also indicated that the inferred feelings were overall more positive when partner's eyes were oriented towards the self. Instead, the interaction term was not significant, $\beta = .01$, $F(1, 1187) = .01$, $p = .927$.

Moderated-Mediation. We found a significant effect of feelings, $b = .35$, 95% CI [.31, .38], $p < .001$, a non-significant effect of pupil size, $b = -.01$, 95% CI [-.11, .09], $p = .902$, and a non-significant effect of gaze, $b = -.09$, 95% CI [-.18, .004], $p = .062$. More importantly, we found no significant interaction between pupil size and gaze target, $b = .17$, 95% CI [-.03, .36], $p = .095$, but a significant interaction between inferred feelings and gaze target, $b = .54$, 95% CI [.47, .61], $p < .001$. The latter interaction proved the moderated-mediation. Gaze target qualified the impact of pupil size on liking by modulating participants' response to the feelings inferred from partner pupil size.

We inspected the moderated-mediation by testing three simple mediations on the three gaze target conditions. When the eyes of the partner gazed at the self, we found a significant total effect of pupil size on liking, $b = .73$, 95% CI [.31, .38], $p < .001$. There was a significant effect of pupil size on inferred feelings, $b = 1.05$, $p < .001$, and a significant effect of feelings on liking, $b = .64$, $p < .001$. The indirect effect was significant, $b = .68$, $z = 8.28$, $p < .001$. Instead, the direct effect showed that the impact of pupil size on liking was no longer significant after inclusion of inferred feelings, $b = .05$, $p = .365$. Then, we focused on disliked other-oriented trials. There was no total effect of pupil size on liking, $b = -.01$, 95% CI [-.16, .14], $p = .919$, a significant effect on inferred feelings, $b = 1.04$, 95% CI [.85, 1.24], $p < .001$, and an effect of feelings on liking, $b = .08$, 95% CI [.02, .14], $p = .007$. As revealed by a Sobel test, $b = .09$, $z = 1.34$, $p = .181$, the indirect effect was not significant. The direct effect was also not significant, $b = -.09$, 95% CI [-.25, .07], $p = .250$.

Analysis on the three separate outcome variables

Experiment 1

Attractiveness. A main effect of pupil partner showed that participants liked partners with dilating pupils more than those with constricting pupils, $F(1, 3138) = 39.23$, $p < .001$. A main effect of gaze orientation also emerged, $F(1, 3138) = 32.27$, $p < .001$, with higher attribution of attractiveness towards partner gazing the participant. Also significant was the interaction between pupil size and gaze orientation, $F(1, 3138) = 438.69$, $p < .001$. Follow-up *t*-tests showed that dilated pupils led to higher attractiveness than constricted pupils when the eyes of the partner were oriented towards the participant, $t(1541.01) = 19.36$, $p < .001$. Instead, when the eyes of the partner were oriented towards the disliked other, dilated pupils lead to significantly lower attribution of attractiveness than constricted pupils, $t(1541.01) = -10.75$, $p < .001$.

Friendliness. We found a main effect of pupils, $F(1, 3139) = 186.88$, $p < .001$, as well as a main effect of gaze, $F(1, 3139) = 32.71$, $p < .001$. Both the effects were in line with what found on general liking. The interaction between pupil size and gaze orientation showed significant, $F(1, 3139) = 376.81$, $p < .001$. Follow-up *t*-tests showed that attribution of friendliness was higher with dilated pupils when the partner gazed the participant, $t(1541.01) = 23.32$, $p < .001$. Instead, when the eyes were oriented towards the disliked other, partners with dilated pupils were perceived less friendly than those with constricted pupils, $t(1541.01) = -4.26$, $p < .001$.

Trustworthiness. We found a main effect of pupil size, $F(1, 3138) = 61.33$, $p < .001$, as well as a main effect of gaze, $F(1, 3138) = 31.16$, $p < .001$. The effects revealed that participants trusted more partners with dilated pupils and partners who looked at them. The interaction between pupil size and gaze orientation showed significant, $F(1, 3138) = 450.90$, $p < .001$. Follow-up *t*-tests showed that dilated pupils in partners who gazed the participant increased the attribution of trustworthiness, $t(1541.01) = 20.89$, $p < .001$. Instead, when the eyes were oriented towards the disliked other, partners with dilated pupils were trusted less than those with constricted pupils, $t(1541.01) = -9.85$, $p < .001$.

Experiment 2

Attractiveness. We found a main effect of pupil size in the expected direction, $F(1, 4738) = 593.68$, $p < .001$. Gaze orientation was also significant, $F(2, 4738) = 8.35$, $p < .001$, indicating lower attractiveness for partners looking at the disliked other compared to both partners looking at the self or at the liked other, $t = -3.61$, $p < .001$ and $t = -3.46$, $p = .002$. There was no difference when comparing participant-oriented and liked other-oriented gaze, $t = -0.16$, $p = .987$. The interaction term was significant, $F(2, 4738) = 150.17$, $p < .001$. Follow-up *t*-tests showed that dilated pupils led to higher attribution of attractiveness than constricted pupils when the eyes of the partner were oriented towards the participant, $t(1542) = 18.91$, $p < .001$, and towards the liked-other, $t(1542) = 22.94$, $p < .001$. The effect of pupil size was not detectable when the eyes of the partner were oriented towards the disliked other, $t(1542) = .00$, $p = 1$.

Friendliness. We found a main effect of both pupil size, $F(1, 4738) = 1079.03$, $p < .001$. A significant effect of gaze orientation, $F(2, 4738) = 6.64$, $p = .001$, revealed lower attribution of friendliness for partners looking at the disliked other compared to both partners looking at the self or at the liked other, $t = -3.29$, $p = .003$ and $t = -3.01$, $p = .007$. There was no difference when comparing participant-oriented and liked other-oriented gaze, $t = -0.28$, $p = .958$. The interaction between pupil size and gaze orientation was significant, $F(2, 4738) = 64.34$, $p < .001$. Follow-up t-tests showed that attribution of friendliness was higher with dilated pupils when the partner gazed the participant, $t(1542) = 20.92$, $p < .001$, as well as the liked-other, $t(1542) = 25.16$, $p < .001$. When the eyes of the partner were oriented towards the disliked other, partners with dilated pupils were still perceived more friendly, but the effect was smaller, $t(1542) = 10.54$, $p < .001$.

Trustworthiness. We found a main effect of both pupil size, $F(1, 4738) = 610.76$, $p < .001$, and gaze orientation, $F(2, 4738) = 7.53$, $p < .001$. The latter effect showed that partners with eyes oriented towards the disliked other were trusted less than those looking at either the participant, $t = -2.42$, $p = .042$, or the liked other, $t = -3.84$, $p < .001$, whilst no difference emerged between participant- and liked other-oriented gaze, $t = 1.42$, $p = .329$. More importantly, we found a significant interaction between pupil size and gaze orientation, $F(2, 4738) = 124.54$, $p < .001$. Follow-up t-tests showed that dilated pupils in partners who gazed either the participant or the liked other increased the attribution of trustworthiness, $t(1542) = 18.76$, $p < .001$ and $t(1542) = 22.16$, $p < .001$, respectively. Instead, when the eyes were oriented towards the disliked other, no effect of pupils emerged, $t(1542) = 1.57$, $p = .117$.