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The Power of Pupil Size in Establishing Trust and Reciprocity

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The eyes are extremely important in communication and can send a multitude of different messages. Someone's pupil size carries significant social information and can reflect different cognitive and affective states that within a social interaction can prove to be particularly meaningful. In 3 studies we investigated the impact of a person's pupil size on how others evaluate that person. In Experiment 1, participants played trust games in the role of investor. The results demonstrate that participants trusted happy compared with angry partners more, as well as those with dilating compared with constricting pupils, to whom they also assigned more positive personality traits including friendliness, attractiveness, and trustworthiness. In Experiment 2, participants played the same trust game, but this time in the role of trustee, where they had to decide to reciprocate and share a financial gain with the investor or to keep it for themselves, and act selfishly. The results show that participants reciprocated more to partners with dilating compared with constricting pupils. In Experiment 3, we found preliminary evidence that these positive behavioral changes are likely to be specifically directed to the virtual partner and do not reflect a general positivity bias. To conclude, pupil size is an important social cue that others implicitly take into account when making social decisions.

Keywords: affect, economic game, social decision making, generosity, social bond

For social species, humans included, acts of prosociality, such as trusting others and reciprocating favors, are fundamental to a healthy social group life. Yet, they are not without risk. Decisions of trust can lead to abuse, betrayal or exploitation and returning a favor might turn out to be just a waste of time, resources, or effort (Balliet & Van Lange, 2013; Parks, Joireman, & Van Lange, 2013; Pruitt & Kimmel, 1977). In some instances, decisions like these concern people we know. In those cases, while making a decision, we think back to comparable previous situations and consider the options in light of the future relationship (King-Casas et al., 2005; Rule, Slepian, & Ambady, 2012). But there are often times where social decisions concern strangers and assessments of trustworthiness are based on a partner's tractable characteristics, such as facial features and emotional expressions (Krumhuber et al., 2007; Stewart et al., 2012; Todorov, Baron, & Oosterhof, 2008; van't Wout & Sanfey, 2008; Willis & Todorov, 2006).

Among the many implicit cues that may inform assessments of someone's trustworthiness, the human eye region stands out as particularly salient and powerful. The eye region provides important social signals and from the first days of life onward, humans are specifically attuned to this region of the face (Farroni, Csibra, Simion, & Johnson, 2002) and spend more time looking at this region compared with their ape cousins (Kano & Tomonaga, 2009). The human eye is unique in that it is surrounded by a relatively complex network of fine muscles (Parr & Waller, 2006) and reveals a large part of its white casting (Kobayashi & Kohshima, 1997), making the whole eye region particularly expressive and communicative (Tomasello, Hare, Lehmann, & Call, 2007). Also, because pupil size is hardly ever voluntary control, humans attend to another's eye region and infer an interaction partner's true intentions and emotions from not only gaze cues or contractions of the muscles around the eyes, but also from pupil size (Hess, 1975).

Notwithstanding the important social signaling function of the pupil (Kret, 2015), research evidence on its possible effects is only beginning to emerge. Early research has shown that pupil size is a sign of youth and fitness and decreases with age (Birren, Casperson, & Botwinick, 1950). Hess (1975) was the first to investigate

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the social potential of pupil size. In a pioneering study, he demonstrated that participants' pupil size positively correlated with their interest level in the object or person they attended to (Hess, 1975). Next, he presented a series of pictures of women. These pictures had been retouched to make the women's pupils larger or smaller than the originals. Despite being unaware of the manipulation, participants liked the woman with the large pupils better, describing her as more feminine, prettier, and softer than the women with small pupils (Hess, 1975). When participants were shown line drawings of an angry and a happy face and asked to draw in the missing pupils, participants drew larger pupils in the happy face and smaller ones in the angry face (Hess, 1975), an effect we recently replicated (Kret, 2018). People with large rather than small pupils are commonly rated as more attractive (Demos, Kelley, Ryan, Davis, & Whalen, 2008); however, the same effect can be obtained with cat eyes (Amemiya & Ohtomo, 2012), making it unlikely that this represents sexual attraction specifically. Overall, the aforementioned evidence suggests that individuals with large pupils are evaluated more positively in a much more general way than was initially assumed.

Previous work has mostly used pictures of eyes and pupils, yet in real life, pupils change in size dynamically and reflect our inner state of mind in an interactive fashion. Imagine looking someone in the eyes and suddenly their pupils start to dilate. This might give the impression that this change was because of you and may therefore be interpreted as social interest. The presentation of static versus dynamic pupils can have potentially important consequences for perception, reflecting traits versus states respectively. In interactive fashion studies, we therefore investigated the effect of dynamically changing pupil sizes on perceived trustworthiness (Kret & De Dreu, 2017; Kret, Fischer, & De Dreu, 2015; Prochazkova et al., 2018; Wehebrink, Koelkebeck, Piest, de Dreu, & Kret, 2018). In the first study, participants played trust games with virtual partners of whom they could only see the eyes; these either held an angry or a happy expression. Within these eyes, the pupils were manipulated to dilate, remain static at an intermediate size or constrict over a stimulus presentation time of 4 s. Importantly, the changes in pupil size did not happen immediately, but began after a static presentation of 1.5 s to create the impression that the pupil change was caused by the participant making eye contact with the observed partner. What was observed was that participants invested more in partners with dilating pupils compared with those with static or constricting pupils. This was especially the case for partners expressing happiness but was also observed in partners expressing anger (Kret et al., 2015). Happiness and anger are both highly arousing emotions, and for the pupil it is natural to dilate during states of arousal, therefore possibly adding to the genuineness of the expression. In a second study we replicated our previous findings in an experiment including partners with neutral expressions (Kret & De Dreu, 2017). In a third study, we revealed that pupil mimicry might be important to boost the typically low levels of trust that are observed in clinical populations such as those with a depression. Finally, in our most recent study, we investigated the neural mechanisms and showed the involvement of the theory of mind network in pupil mimicry (Prochazkova, in press). Together, this work shows that partners with pupils that dilated dynamically were better trusted, independent of the emotional expression the eyes conveyed, and through the recruitment of social brain areas. Although these studies provided first evidence for a relationship between pupil size and trust, they also raised a number of questions, the three most important of which will be addressed in three new experiments described in the current article.

The first question that our previous work could not address directly is whether the boost in trust that was generated by looking into a pair of eyes with dilating pupils, was specifically related to trust as measured in the trust game. It is highly possible that these dilated pupils simply made the individuals appear more attractive (Demos et al., 2008), or friendlier (Hess, 1975) and that this consequently also had an impact on perceived trustworthiness. In Experiment 1, we aimed to address this question, as well as replicate and extend our previous findings. As such, in addition to playing the trust game, participants rated their partners on trustworthiness, attractiveness and friendliness scales. The purpose of these explicit ratings next to the trust game was to verify which one of these measures was most strongly predicted by the partners' pupil size. On the basis of our previous studies we expected that participants would invest more in partners with dilating pupils than in partners with constricting pupils (Kret & de Dreu, 2017; Kret, Fischer, & de Dreu, 2015; Prochazkova et al., 2018; Wehebrink et al., 2018). Moreover, we predicted that they would also evaluate partners with dilating pupil dilating pupils more positively than partners with constricting constricting pupils. As we will demonstrate, the strongest relationship was observed during the trust game, a relationship we further explore in Experiment 2 in a new group of participants. In that experiment, the central research question was whether this positive relationship between a partners' dilating pupils and participants' investments during trust games would also work the other way around. In other words, would participants reciprocate more to a partner with dilating pupils? In Experiment 2, we investigated the possible effects of partner's pupil size on decisions of reciprocation. Participants played the trust game in the role of trustee and decided to reciprocate all or part of their gain with the investor, their virtual partner. The third question, which we address in Experiment 3, was whether looking into his or her partner's dilating pupils would create a target-specific positive impression, or make them feel good in general. If this were the case, we should also see that greater trust is extended to other people, not only the partner with dilating pupils. Thus, in Experiment 3, a new group of participants saw the same eyes as in the previous experiments, but here they were completely irrelevant to the task and presented next to a photograph of their virtual interaction partner, with whom they played the trust game. We predicted that participants this time would not be influenced by the pupillary changes in the eyes of the distracting stimuli (i.e., a bystander), which would suggest that the putative effects in Experiments 1 and 2 concern the virtual partner.

Experiment 1

In this experiment we investigated the effects of partner's emotional expression and pupillary changes on participants' decisions to invest in a partner or not. In addition, participants evaluated a partner in terms of friendliness, trustworthiness and attractiveness. Although these measures are related to each other, the goal was to verify which of these measures were most strongly influenced by partner's pupil size.

Method

Participants. Fifty participants (18 males), aged 22.6, ranging from 18.0 to 25.7 years old, took part in this experiment at the University of Amsterdam. This sample size is similar to our previous studies (Brambilla, Biella, & Kret, 2018; Kret et al., 2015; Kret & De Dreu, 2017; Prochazkova et al., 2018; van Breen, De Dreu, & Kret, 2018; Wehebrink et al., 2018). The current study holds a 2 × 3 design. The experimental procedures were in accordance with the Helsinki Declaration and approved by the Ethical Committee of the Faculty of Behavioral and Social Sciences of the University of Amsterdam. Participants provided written informed consent prior to the experiment and received full debriefing and performance-contingent payout upon completion of the study. Two participants were excluded because they repeatedly pressed the same button with very quick response times (for similar outlier-criteria, see also Kret & De Dreu, 2017; Kret et al., 2015; Prochazkova et al., 2018; van Breen et al., 2018). There are arguments for and against leaving out these participants, but importantly, including or excluding these participants did not affect the significance of our results. All of the data from our experiment, including that of these two participants, can be freely downloaded at Harvard Dataverse Kret (2018).

Procedure and experimental tasks. The procedure and experimental tasks closely mirrored those used in our earlier work (Kret & De Dreu, 2017; Kret et al., 2015; Prochazkova et al., 2018; Wehebrink et al., 2018; see Figure 1). Upon arrival in the laboratory, participants provided informed consent and were seated at a 65-cm distance from the computer screen. They read instructions for the trust game, which we referred to as an ‘investment task’; we never mentioned the word ‘trust.’ Participants were told that they would be asked to decide to invest between €0 and €10 in another player, their partner, on a series of investment trials each time with a different partner (see the following text). We further explained that investments would be tripled and matched to the decision of their partner (return nothing, some specific amount, or everything), with whom they were paired in that trial. Participants were told that they would not receive feedback regarding partner decisions during the experiment, but that investments and partner choices would be matched at the end of the experiment. Three practice questions verified that participants understood the trust game and the consequences of their decisions.

We then informed participants that we had recordings of their partners who participated on a previous occasion, and that prior to making decisions they would be shown short clips of these recordings. Each trial started with the presentation of a fixation cross (500 ms) followed by an image of the interaction partner’s eyes with dilating or constricting pupils and either an angry, neutral or happy expression (4,000 ms). Next, a text screen appeared where participants were asked to decide on how much they wanted to transfer. After that, the following questions with a 1 to 10 rating scale were presented in random order: (1) How attractive is the observed person? (1 = *not attractive at all*, 10 = *very attractive*), (2) How friendly is the observed person? (1 = *not friendly at all*, 10 = *very friendly*), (3) How trustworthy is the observed person? (1 = *not trustworthy at all*, 10 = *very trustworthy*).

Participants made investment decisions and partner evaluations in 96 trials in total. Trials differed on the emotion displayed (anger, happy, neutral) and partner pupil (dilating, constricting). Accordingly, for each emotion and partner pupil, we had 16 distinct trials. Trials were presented in a random order. After the experiment, we checked whether participants were aware of our hypotheses. Although the pupillary changes were noticeable to participants and sometimes mentioned by the participants, none of the participants provided a correct answer to this question, making it unlikely that they responded in a socially desirable manner.

Stimuli. To create virtual partners in the trust game, pictures of four men and four women (former students of the University of Amsterdam) with angry, happy, and neutral expressions were selected from the Amsterdam Dynamic Facial Expression Set (ADFES; Kret et al., 2015; van der Schalk, Hawk, Fischer, & Doosje, 2011). Pictures were standardized in Adobe Photoshop, turned to gray scale, and cropped to reveal only the eye region. After cropping each stimulus, everything between the eyelashes (eye-white, iris, and pupil) was erased (see Figure 1a). Next, the average luminance and contrast were calculated per picture, and each picture was adjusted to the mean. The eyes were then filled with new eye-white and irises, based on one iris pair with an intermediate color from one picture, and an artificial pupil was added in Adobe After Effects. To emphasize the convex/bold shape of the eye and increase naturalness, the eye-white directly around the iris was made brighter than the eye white in the outer edges of the eye. For clarification, the exact same eye-template was used for all stimuli, all in gray scale. After static presentation for 1,500 ms, the partner’s pupil, shown in the life-size picture dilated or constricted within the physiological range of 3 mm to 7 mm during another 1,500 ms (always from 5 mm to 7 mm or from 5 mm to 3 mm). In the final 1,000 ms of stimulus presentation, the pupils remained static at their maximum (7 mm) or minimum size (3 mm). To increase ecological validity, a slightly trembling corneal reflection was added and although the pupil dilation or constriction was linear, the edges were rounded off with an exponential function to smoothen the change (natural formula implemented in Adobe After Effects). These videos have been used in our earlier studies (Brambilla et al., 2018; Kret & de Dreu, 2017; Kret et al., 2015; Prochazkova et al., 2018; van Breen et al., 2018; Wehebrink et al., 2018). We chose to use only the eye regions of the faces, because we wanted to ensure that participants attended to the eyes of the stimulus. If the whole face is presented, this attracts fixations to the mouth and nose region of the face. Not only does this reduce the time spent attending to the eyes, but it would do so differently depending on the emotional expression of the face (Eisenbarth & Alpers, 2011). In other words, using only the eye region reduces ecological validity, but gives much more experimental control (Kret & De Dreu, 2017; Kret et al., 2015; Kret, Tomonaga, & Matsuzawa, 2014; Prochazkova et al., 2018; van Breen et al., 2018).

Participants’ investment decisions were coupled with actual decisions of trustees ($N = 15$) from the same university (two males). These 15 participants acted in the role of trustee and were given a form with 10 investment decisions of others (€0 to €10) and asked how much they would reciprocate given a certain investment. These back-transfer decisions were randomly chosen and paired with those made by participants in the main experiment, to calculate actual

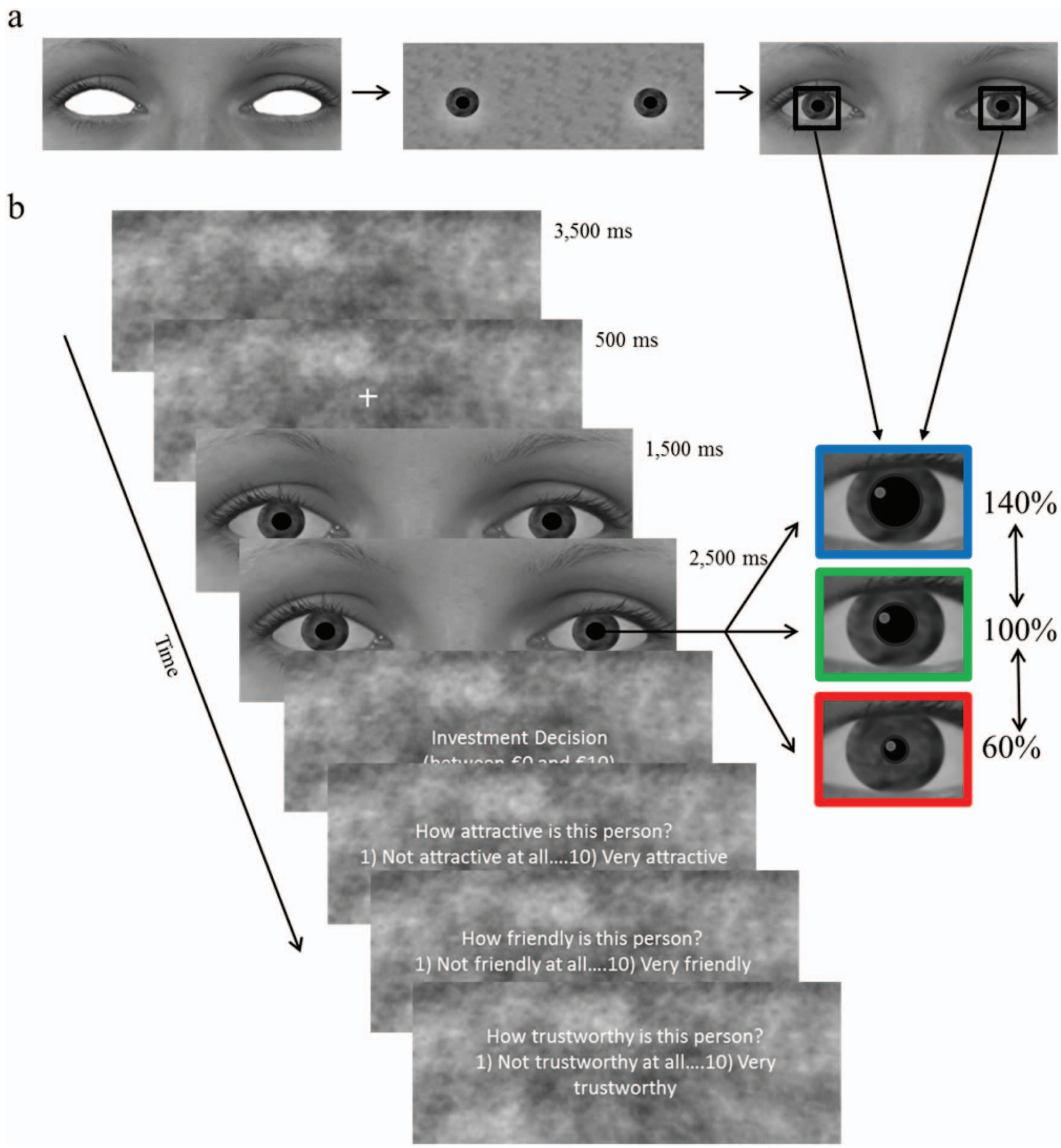

Figure 1. Stimulus characteristics (a) and sample trial sequence (b). To create partner stimuli, we removed the eyes from pictures of the eye regions of faces and then added the same eye white, iris, and pupil to each stimulus (independent of partner's group or emotion). In each trial, a scrambled image of a stimulus was presented for 4,000 ms. The scrambled image was then replaced by the stimulus itself. In all conditions, the stimulus remained static for the first 1,500 ms, but in the dilation and constriction conditions, the pupils gradually changed in size over the following 1,500 ms and then remained at that size during the final 1,000 ms (in the static condition, shown here, pupils remained at the same size throughout the trial). Next, a screen appeared asking participants to decide to transfer an amount between €0 or €10 to their partner. Finally, three questions followed on how the partner was perceived. These appeared in random order. In sum, we examined the relation between changes in partner pupil size, the amount that participants invested and the impression they got from their partner. See the online article for the color version of this figure.

earnings from the trust decisions. For each trial we randomly drew a decision to calculate participants' earnings after the experiment was over (i.e., no feedback between trials was given).

Statistical analysis. Data were analyzed in a two-level generalized mixed model, implemented in SPSS Version 20 (IBM statistics). The 96 trials (Level 2) were nested within participants (Level 1). Emotion (angry, happy, and neutral) and partner pupil (dilating or constricting) and their interaction were included as fixed factors and the individual intercept as a random factor. Although a traditional repeated measures analysis of variance (ANOVA) on averaged data yielded very similar results, the two major advantages of the current approach are that (a) intraindividual variance was maintained and (b) it allows for the inclusion of a random intercept. This random intercept was significant and explained a substantial amount of the variance that is present in the data. The multilevel approach allows all sampled data points to be included in the analysis without the necessity of averaging over trials, as is common in for instance, an ANOVA. Therefore, all variance in the data is maintained while still accounting for independence in the data. The model-procedure always starts with a full model that includes all fixed factors, including interactions. Via loglikelihood tests, we determined whether dropping a nonsignificant factor improved model fit or significantly worsened it, in which case the nonsignificant factor was kept. After specifying the fixed effects, model building proceeded with statistical tests of the variances of the random effects.

Results

Investment decision. The dependent variable was participants' level of investment. Fixed factors included partner pupil size, partner emotion and their interaction. A random intercept was included for each subject. Replicating our previous studies (Kret & De Dreu, 2017; Kret et al., 2015; Prochazkova et al., 2018), a main effect of pupil partner showed that participants invested more in partners with dilating compared with constricting pupils, $F(1, 4.696) = 307.349$, $p < .001$. A main effect of partner emotion, $F(2, 4.696) = 593.260$, $p < .001$, showed that more money was invested in partners with a happy compared with angry, $t(4.696) = 31.811$, $p < .001$, or compared with a neutral expression, $t(4.696) = 4.610$, $p < .001$. The difference between anger and neutral was significant as well, $t(4.696) = 27.304$, $p < .001$. As demonstrated by an interaction effect, more money was invested in partners with dilating compared with constricting pupils, especially when the partner expressed happiness, $F(2, 4.696) = 15.704$, $p < .001$. Follow-up t tests showed that the difference between constricting and dilating pupils was highly significant in all three emotion conditions (anger: $t[4.696] = 5.803$, $p < .001$; neutral: $t[4.696] = 11.054$, $p < .001$ happy: $t[4.696] = 13.490$, $p < .001$). T tests comparing the different emotion categories within the two partner pupil conditions showed that the differences between emotion conditions were significant across all comparisons, with higher investments following partners with dilating pupils and happy compared with angry or neutral conditions (happy–anger: $t[4.696] = 26.330$, $p < .001$; happy–neutral: $t[4.696] = 4.505$, $p < .001$) and lower following angry compared with neutral or happy conditions (anger–neutral: $t[4.696] = 21.884$, $p < .001$; anger–happy: $t[4.696] = 26.330$, $p < .001$). On similar lines, for partners with constricting pupil sizes, investments were higher following partners with happy compared with angry or neutral expressions (happy–anger: $t[4.696] = 18.648$, $p < .001$; happy–neutral: $t[4.696] = 2.005$, $p = .045$) and lower following angry compared with neutral or happy expressions (anger–neutral: $t[4.696] = 16.718$, $p < .001$; anger–happy $t[4.696] = 18.648$, $p < .001$) All means and standard errors are displayed in Figure 2.

Attractiveness rating. The dependent variable was participants' rating of partner's attractiveness (1 to 10) and the fixed factors the same as before. There was a main effect of partner pupil, $F(1, 4.697) = 14.780$, $p < .001$. Participants found partners with dilating compared with constricting pupils more attractive. A main effect of partner emotion showed that happy partners were found more attractive than angry or neutral partners, $F(2, 4.697) = 324{,}720$, $p < .001$; happy compared with angry, $p < .001$, happy compared with neutral, $p = .025$ (see Figure 2). The interaction was not significant. T tests comparing attractiveness ratings following partners with constricting pupils were lower when the expression showed anger compared with a neutral or happy expression (respectively, anger–neutral: $t[4.695] = 14.003$, $p < .001$; anger–happy: $t[4.696] = 15.458$, $p < .001$). Similar emotion effects were observed when partner's pupils dilated with lower attractiveness ratings following those with an angry compared with neutral or happy expression anger–neutral: $t(4.695) = 15.548$, $p < .001$; anger–happy: $t(4.695) = 17.155$, $p < .001$. The difference between happy and neutral was not significant in either pupil condition (ps $\geq .099$, though following the expected trend). Further follow-up tests revealed lower attractiveness ratings for partners with constricting rather than dilating pupils in the happy and neutral condition (happy: $t[4.695] = 2.846$, $p < .001$; neutral: $t[4.695] = 2.714$, $p < .001$), but not in the anger condition ($p = .268$). All means and standard errors are displayed in Table 1.

Friendliness rating. The dependent variable was participants' rating of partner's friendliness (1–10). A main effect of partner pupil showed that participants found partners with dilating compared with constricting pupils friendlier, $F(1, 4.695) = 107.707$, $p < .001$. Happy partners were judged as friendlier than angry or neutral partners, as shown by a main effect of partner emotion, $F(2, 4.695) = 898.080$, ps $< .001$. The interaction showed that especially partners with a happy expression were rated friendlier when their pupils were dilating compared with constricting, $F(2, 4.695) = 6.013$, $p = .002$. T tests comparing friendliness ratings following partners with constricting pupils were lower when the expression showed anger compared with a neutral or happy expression (respectively, anger–neutral: $t[4.695] = 21.380$, $p < .001$; anger–happy: $t[4.695] = 25.744$, $p < .001$). Similar emotion effects were observed when partner's pupils dilated with lower friendliness ratings following those with an angry compared with neutral or happy expression (anger–neutral: $t[4.695] = 25.162$, $p < .001$; anger–happy: $t[4.695] = 30.177$, $p < .001$). The difference between happy and neutral was significant too (dilating, happy–neutral: $t[4.695] = 5.083$, $p < .001$; constricting, happy–neutral: $t[4.695] = 4.456$, $p < .001$). Further follow-up tests revealed lower friendliness ratings for partners with constricting rather than dilating pupils in all three emotion categories (anger: $t[4.695] = 3.200$, $p = .001$; happy: $t[4.695] = 7.689$, $p < .001$; neutral: $t[4.695] = 7.078$, $p < .001$). All means and standard errors can be found in Table 1.

Trust rating. The dependent variable was participants' trustworthiness rating. A main effect of partner pupil showed that participants trusted partners with eyes with dilating compared with constricting pupils more, $F(1, 4.695) = 285.520$, $p < .001$. Happy compared with angry or neutral partners were better trusted, as again shown by a main effect, $F(2, 4.695) = 515.715$, ps $< .001$. The interaction showed that although partners with dilating compared with constricting pupils were generally found more trustworthy, this effect was strongest when the partner expressed happiness, $F(2, 4.695) = 5.395$, $p = .005$. T tests comparing trust ratings following partners with constricting pupils were lower when the expression showed anger compared with a neutral or happy expression (respectively, anger–neutral: $t[4.695] = 16.933$, $p < .001$; anger–happy: $t[4.695] = 18.342$, $p < .001$. Similar emotion effects were observed when partner's pupils dilated with

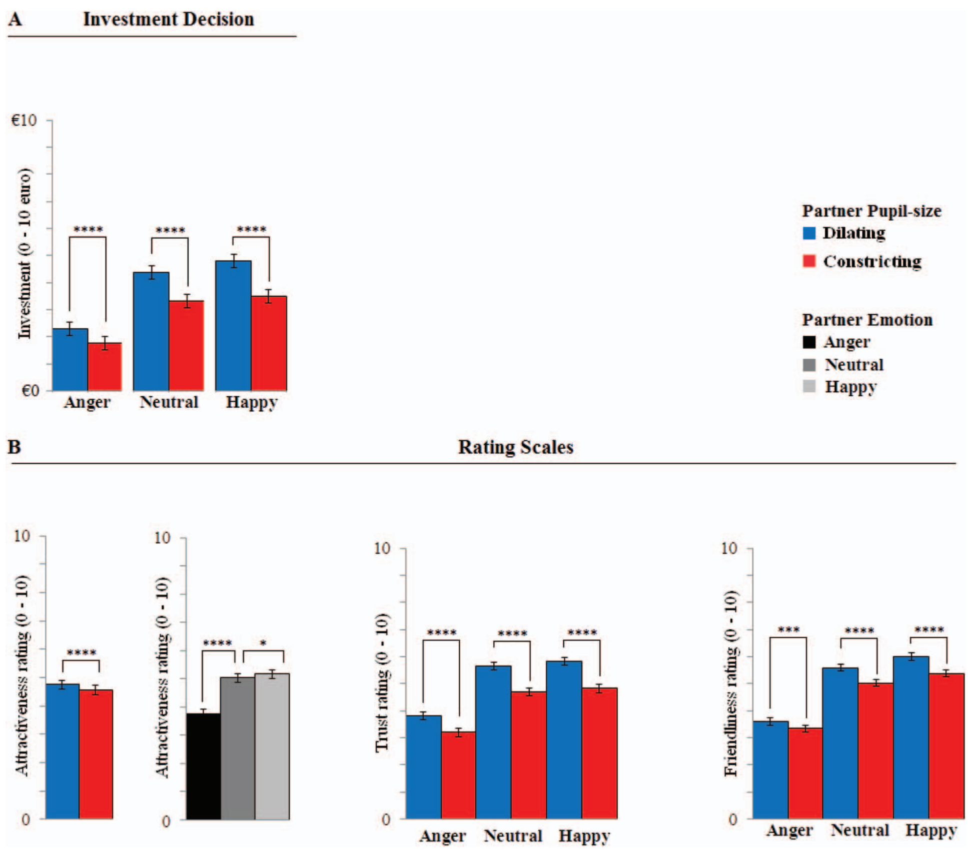

Figure 2. Panel A: Investment decisions regarding partners showing an angry, neutral or happy expression in their eye region with either dilating or constricting pupil size. Panel B: Rating scales assessing attractiveness, trust and friendliness. Error bars represent the standard error of the predicted means. Asterisks indicate significant differences. Participants' investments as well as the evaluations of their partners regarding attractiveness, trustworthiness and friendliness were influenced by the emotional expression of the partner and their pupil size. See the online article for the color version of this figure.

lower investments following those with an angry compared with neutral or happy expression, $t(4.695) = 20.728$, $p < .001$; anger–happy: $t(4.695) \geq 22.420$, $p < .001$. The difference between happy and neutral was not significant in either pupil condition ($ps \geq .08$, though following the expected trend). Further follow-up tests revealed lower trust ratings for partners with constricting rather than dilating pupils in all three emotion categories (anger: $t[4.695] = 7.096$, $p < .001$; happy: $t[4.695] = 11.175$, $p < .001$; neutral: $t[4.695] = 10.965$, $p < .001$). The key findings are displayed in Figure 2.

Conclusion

Experiment 1 replicates our earlier findings that partners with dilating pupils are trusted more than partners with constricting pupils. The effect of constricting pupils was particularly detrimental for partners with a happy expression. This experiment extends our previous findings by showing that partner's pupil size not only impacted on perceived trustworthiness, but in a similar way positively impacted on other social judgments including attractiveness and friendliness. Hence, observing large pupils does not boost trust specifically, but rather gives participants a more general positive impression. Another conclusion to be drawn from this study is that the strongest results were obtained when participants played the trust game. For that reason, in the next experiment, we build on Experiment 1 and continue with the trust game. Whereas participants in Experiment 1 played the role of investor, in the next experiment the roles are switched and participants now play the role of trustees. In Experiment 2, we test the hypothesis that participants in the role of trustee would reciprocate most to partners with dilating pupil sizes and least to those with constricting pupil sizes.

Experiment 2

In this next experiment, we investigate the relationship between a partner's pupillary changes and participants' tendency to reciprocate. Here, participants play the role of trustee and decide to reciprocate monetary gains to their partners or not. Experiment 1 showed that the outcomes for trustworthiness, friendliness and attractiveness were very similar, although the strongest results were obtained with the trust game. Moreover, pupil size had a very similar effect on these judgments across the three emotion conditions. Therefore, we decided to limit the number of conditions maximally in Experiment 2. First, as the trust game yielded the strongest results, we continued with that approach. Second, as we were mostly interested in the effect of pupil size on decisions and the effects held across 'emotional conditions' we decided to continue with neutral expressions. Because in Experiment 1 we could only compare the pupil dilation from the pupil constriction condition and not pull apart the unique effects of these conditions, a third control condition was added, where partners' pupils remained static over stimulus presentation time.

Method

Participants. Forty participants (15 males), aged 23.4 years on average, ranging from 18 to 30 years old, took part in this experiment at the University of Amsterdam. The sample size was somewhat smaller than in Experiment 1 but was considered sufficient because of the lower number of within-subjects conditions. The sample size was not predetermined, but was the result of the laboratory that was reserved for a short, fixed period of time and depended on the number of students that registered. The experimental procedures were in accordance with the Helsinki Declaration and approved by the Ethical Committee of the Faculty of Behavioral and Social Sciences of the University of Amsterdam. Participants provided written informed consent prior to the experiment and received full debriefing and performance-contingent pay-out upon completion of the study. Six participants were excluded as they always made the same decision.

Stimuli. The stimuli were similar to those in Experiment 1 but only included neutral expressions (see also Kret & De Dreu, 2017). There were 54 trials in total, 18 per partner pupil condition, and each trial showed a unique stimulus. The stimuli showed the eye region of 18 people, nine male and nine female. All had neutral expressions and all were presented once with constricting pupils, once with static and once with dilating pupils. As in Experiment 1, all participants saw the same stimuli, except that here, they saw 18 different actors (half female). Each unique partner was presented three times, once with dilating pupils, once with static pupils and once with constricting pupils.

Procedure. Upon arrival in the laboratory, participants provided informed consent, were seated at a 65-cm distance from the computer screen. They were instructed about the trust game in similar ways as in Experiment 1, but were assigned the role of trustee rather than investor. They were told that their partners participated in this game on an earlier occasion and had then played the role of investor while being videotaped. The participants in this experiment had to decide how much they would reciprocate to their partner, who, from an endowment of €6, "invested" 0, 2, 4, or 6 in the participant. Partner investments were randomized and participants received the amount of the investment multiplied by the factor 3. Participants received 54 trials in which they played with 18 virtual partners (half male) represented by their eye region with pupils that were dilating, constricting or remained static. Overall the number of trials per investment condition was equally distributed over participants and the minimum number of trials per partner investment "decision" was 10 (average 13, $SD = 1$). Following the partner's decision, participants then received 0, 6, 12, or 18 € respectively, on top of the €6 they already had. If the partner invested 0 €, participants had the option to reciprocate 0, 2, 4, or 6 €. If the partner invested €2, participants received €6 on top of their €6 endowments, had a larger budget and thus could therefore reciprocate 0, 4, 8, or 12 €. If the partner invested €4, participants could reciprocate 0, 6, 12, or 18 €. Finally, if the partner invested everything, that is, €6, participants could reciprocate 0, 8, 16, or 24 €. See Table 1 for the four possible situations.

Statistical analysis. We computed the proportion of reciprocation by dividing the amount participants reciprocated by the amount of money participants had in their pocket after receiving the partner investment. For example, if a partner invested €4, the participant's budget was $4 \times 3 + 6 = 18$ € and their choice options were to reciprocate 0, 6, 12, or 18 €. If they reciprocated €6, then the proportion of what they invested was $6/18 = 0.33$ (33%). For simplicity, we call this variable reciprocity. Data were analyzed in a generalized mixed multilevel model with 54 trials nested within individual subjects. Thus, on each trial, the participant had reciprocated a certain amount and the model investigated to what extent this decision was predicted by partners' pupil size. A random intercept was included for each subject to account for variance in the intercept that are related to individual differences in reciprocity. Partner pupil was the only within-subject factor and included as a fixed factor which was coded as follows: -1 = constricting, 0 = static, 1 = dilating. As our dependent variable Reciprocity was skewed, we selected a gamma probability distribution (log link function), which specifies Gamma as the distribution and log as the link function.

Results

Reciprocity (the proportion of reciprocation) was analyzed in a multilevel model with only one fixed predictor, partner pupil and a

Table 1
Reciprocity Choice Options

Participant and investor endowments	Investor decides to invest	Participant Receives Investment × 3	Participant Endowment + Investment × 3	Participant can reciprocate to investor
6 and 6 (€)	0	0	6	0, 2, 4, or 6
6 and 6	2	6	12	0, 4, 8, or 12
6 and 6	4	12	18	0, 6, 12, or 18
6 and 6	6	18	24	0, 8, 16, or 24

Note. Participants played the role of trustee and could decide whether they wanted to reciprocate earnings with the investor. The amount that they could send to the investor depended on how much the investor invested. The reciprocation options in the final column were presented to participants so that they could choose one among the four options.

random intercept for subject. A main effect of partner pupil, $F(1, 1.480) = 3.549$, $p = .029$, showed that participants reciprocated more to partners whose pupils dilated ($M \pm SE = 0.439 \pm 0.021$) versus constricted ($M \pm SE = 0.417 \pm 0.020$ $p = .009$); static pupils took an intermediate position ($M \pm SE = 0.425 \pm 0.021$; static-dilate: $p = .105$; static-constrict: $p = .101$). For exploratory purposes, we also investigated whether the initial investment of the partner investor influenced the extent to which participants reciprocated. This did indeed have an effect. The larger the investment, the more participants reciprocated relatively, $F(1, 1.481) = 79.772$, $p < .001$. There was no interaction between investment and partner pupil ($p = .614$).

Conclusion

Experiment 2 showed that observing a partner with dilating pupils boosts generosity and made participants reciprocate more of their financial gain than during interactions with partners with constricting pupils. In contrast to what we predicted, the difference between the dilating and constricting conditions with the static condition, were not significant, although they were numerically consistent with our expectations (dilating > static > constricting). Together with Experiment 1, this shows that looking into eyes with dilating pupils boosts investments, ratings of trustworthiness, friendliness and attractiveness and also increases reciprocity. However, it is undetermined whether these increases are specifically related to how the participant views the partner or whether there is a more general enhancement of positive affect that spills over to the partner (i.e., seeing the world through rose-coloured glasses). To rule that out, the next experiment aims to pull apart general positive effects from positive effects on the evaluation of the partner.

Experiment 3

In this control experiment, participants played the trust game in the role of investor when they were presented with partners who had a full face that portrayed a neutral expression with a direct gaze. Right beside the partner, a pair of eyes was presented with pupils that changed in size, similar to the stimulus materials used in Experiments 1 and 2, except that the gaze of these eyes was either looking at the participant or looking at the partner (see Figure 3). We predict that the observed changes in pupil size will not influence the trustworthiness ratings of the partner. If this is true we could infer that the positive effects of dilated pupils obtained in Experiments 1 and 2 are limited to the interaction partner and do not spread to other people.

Method

Participants. Thirty-two participants (six males), aged 23.8 years on average, on average, ranging from 18 to 49 years old, took part in this experiment at the University of Amsterdam. The sample size was lower than in the previous two experiments as the sole goal of this straightforward experiment was to rule out an alternative explanation for the interpretation of the results we obtained in Experiments 1 and 2. The experimental procedures were in accordance with the Helsinki Declaration and approved by the Ethical Committee of the Faculty of Behavioral and Social Sciences of the University of Amsterdam. Participants provided written informed consent prior to

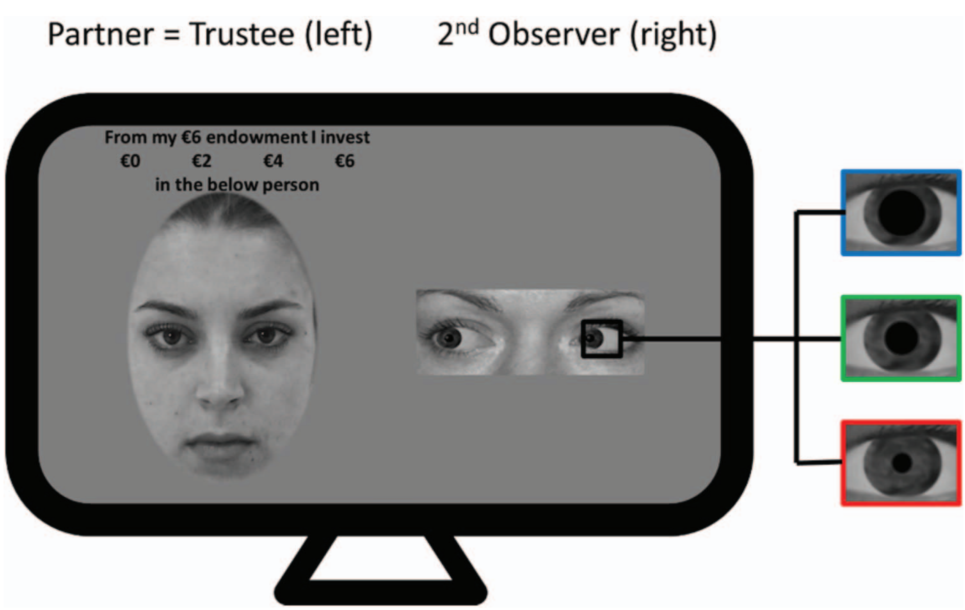

Figure 3. Participants decided to make a monetary investment in the partner, here presented on the left, of whom always the whole face was visible. Participants were told that they did not have to do anything with the pair of eyes (here displayed on the right) in which the pupils dilated, remained static or constricted over stimulus presentation time. In the preceding text, the whole face was presented at the same time as the whole face and eyes, but 4 s after stimulus onset, that is, when the pupils in the eyes had changed and remained at maximum or minimum size for one second (if they had changed in size at all), another screen appeared where participants were asked directly to make an investment decision, Thus, participants did not make overt investment decisions during stimulus presentation, but only indicated their choice afterward. See the online article for the color version of this figure.

the experiment and received full debriefing and performance-contingent pay-out upon completion of the study. Two participants were excluded because they always selected the same response option.

Stimuli. Participants always saw two stimuli simultaneously on the computer screen. One stimulus consisted of a pair of eyes with a neutral expression, similar to those in Experiment 2, but with direct or averted gaze. Next to these eyes of eight different people (half male), a picture was presented depicting the full face of the partner, that is, the trustee. As we wanted to have a large variety of trustee-faces and present each participant one particular face only once, we included faces from different face sets including ADFES (van der Schalk, et al., 2011), McArthur (Tottenham et al., 2009) and faces used in our previous work (Kret & Tomonaga, 2016). In total, we included 72 unique faces, half male, so that on each trial, they saw a unique face presented next to a pair of eyes with dilating, constricting or static pupils and the gaze either directed at the trustee (to the side) or at the participant (frontal). The gender of the whole face and of the eyes was always the same (i.e., female eyes paired with female faces, male eyes paired with male faces). See Figure 3.

Procedure. Upon arrival in the laboratory, participants provided informed consent, completed medical screening, and were seated at a 65-cm distance from the computer screen. In a series of 72 investment trials they would be asked to decide to invest between €0, €2, €4, or €6 in their partner. Investments would be tripled and matched to the decision of their partner (return nothing, some specific amount, or everything), with whom they were paired in that trial. Three practice questions verified that participants understood the game and the consequences of their decisions.

Participants were told that next to seeing the partner with whom they played, they would see a pair of eyes of someone else (observer eyes), which they could ignore if they wished, as these were irrelevant for the game. As in Experiment 1, they were told that their partners, represented by the whole face, participated in this game on an earlier occasion and had then played the role of trustee. Partner payments were indeed based on the same back-transfer decisions of the 15 students described in Experiment 1. It was (verbally and via the instruction screen) made very clear to participants that they had to base their investment decision on the partner of whom the full face was shown, as this was the person who had participated earlier and to whom decisions were coupled, and not on the pair of eyes presented next to it.

Each trial, (which is a single game), started with the presentation of a fixation cross presented on a scrambled image of the eye region and on the location the eye region would emerge later on in the trial (500 ms), followed by an image of the partner's face and the observer's eyes (4,000 ms). To improve clarity, the text with how much participants wanted to invest was shown right above the partner's face. After that, a text screen appeared with the text "From my €6 endowment, I invest €0, €2, €4, or €6." Participants had been told from the beginning that they were supposed to only make their decision once this screen appeared. Trials were presented in random order.

Observer's eyes were from 8 different actors (half male), and had dilating, static or constricting pupils which were either gazing at or away from the partner, or directly gazing at the participant. This made 72 unique stimuli that were randomly paired with 72 unique partner faces. The location of the partner face (left/right) and condition of observer eyes were counterbalanced.

Statistical analysis. Data were analyzed in a two-level generalized mixed model, with the 72 trials nested within participants. Observer gaze direction at partner (presented at the left or right side of his face, gazing right or left respectively) or gaze directed at the participant (frontal) and observer pupil size (dilating, static, constricting) and their interaction were included as fixed factors. The intercept was random.

Results

Investment decisions, measured in the trust game, were analyzed in a model with observer gaze direction and observer pupil size as fixed factors. A random intercept for each subject was included. The mean investment was €2.05 ($SE = 0.20$). In line with our prediction, there was no significant main effect for observer pupil ($p = .12$). In addition, there was no main effect for observer gaze direction ($p = .380$) and no interaction effect between these two factors ($p = .328$).

Conclusion

Experiments 1 and 2 showed clear effects of partner's pupil size on participants' behavior, influencing that positively. In the current experiment we aimed to investigate whether that positive behavioral change was directed specifically to the partner, or was more general and would spill over to another individual. We observed no spill-over effects in Experiment 3, which strongly suggests that observing someone's pupils dilate, really makes one more positive toward that particular person and not more positive in general.

General Discussion

The human eye is ideally prepared for communication (Kobayashi & Kohshima, 1997; Tomasello et al., 2007) and from infancy onwards, it attracts attention seamlessly (Farroni et al., 2002). The eyes are used a lot during communication. Emotion-driven complex musculature changes, such as the raising and lowering of eyelids and eyebrows enables perceivers to decode emotions from just the eye region (Baron-Cohen, Wheelwright, & Jolliffe, 1997; Kret & de Gelder, 2012). Moreover, gaze cues express intentions and wishes (Tomasello et al., 2007). Another type of eye signal that has regained scientific attention in the past decade is the changes in pupil size that for example reflect whether a person is aroused and alert or bored and fatigued (Bradley, Miccoli, Escrig, & Lang, 2008; Kinner et al., 2017; Kret, Roelofs, Stekelenburg, & de Gelder, 2013; Kret & Sjak-Shie, 2018; McGarrigle, Dawes, Stewart, Kuchinsky, & Munro, 2017; Morad, Lemberg, Yofe, & Dagan, 2000). Here we describe three experimental studies that investigate the impact of a person's pupil size on how other people evaluate that person.

In Experiment 1 through 3 we investigated the effects of partner's emotional expression and pupillary changes on participants' decisions during trust games where they played the role of investor (Experiments 1 and 3) or trustee (Experiment 2). Moreover, we investigated whether participants evaluated their partners differently in terms of friendliness, trustworthiness and attractiveness when partners' pupils either dilated or constricted. The findings show prosocial effects of partner's dilating pupil sizes in terms of decisions of trust and evaluations of trustworthiness, friendliness and attractiveness (Experiment 1) and acts of reciprocity (Experiment 2). Importantly, the results of Experiment 3 suggest that these positive behavioral changes were related to the interaction partner and did not result from a more general effect that would have spilled over to other observed individuals in the presence presence of the interaction partner. Overall, the results of the three experiments together show that pupil size not only reflects our inner feelings and states of mind, but is also an important social cue that others do take into account when making social judgments and decisions to trust someone or to share financial gains. Our results fit with recent proposals that pupillary exchanges might serve as an ancient bonding mechanism (Kret, 2015; Kret & De Dreu, 2017; Kret et al., 2014, 2015; Prochazkova & Kret, 2017; Prochazkova et al., 2018; Wehebrink et al., 2018). In the following text, we describe the implications of these findings.

Already in the 17th century, Italian women were well aware of the positive effects of dilated pupils and used atropine-containing eye drops, which induced pupil dilation. Nowadays all sorts of colored contact lenses, some with a large black center, are used to create the look of a large, glossy, doll-like pupil (Allard, Wadlinger, & Isaacowitz, 2010; Bitsios, Langley, Szabadi, & Bradshaw, 1996; Bradley et al., 2008; Kret, Roelofs, et al., 2013; Kret, Stekelenburg, Roelofs, & de Gelder, 2013; Lorenz, 1943). Also, Disney illustrators and Japanese manga-artists have long used the effect of pupil size in their cartoons (Bambi has large pupils, the untrustworthy big bad Woolf has only pin-points). Even our language has expressions that reflect this folk knowledge that dilated pupils are "good": "his eyes were like saucers" or "his eyes were pinpoints of hate," "beady-eyed," "bug-eyed," or "hard-eyed." The ethologist Konrad Lorenz proposed the baby schema (*Kindchenschema*), which is a set of infantile physical features such as the large head, round face and big eyes which are perceived as cute and motivates caretaking behavior, with the evolutionary function of enhancing offspring survival (Lorenz, 1943). Large pupils also fit in this baby schema and this might be the core mechanism that yielded the positive evaluations in our studies. Research supporting this view has shown that young children generally have larger pupils than adults and also that older adults have smaller pupil sizes than younger adults (Bitsios et al., 1996). In addition, it has been demonstrated that the pupil dilates in response to emotional faces (Bradley et al., 2008; Kret, Roelofs, et al., 2013; Kret, Stekelenburg, et al., 2013) but that this response declines with age (Allard et al., 2010). Thus, large pupils seem to be associated with youth, triggering social approach and bonding (Brambilla et al., 2018). Perhaps, this ancient bonding mechanism is further facilitated by the mimicry of pupil size, which may help us to process this cue better. Indeed, a recent fMRI study shows that during pupil mimicry, regions in the brain that are commonly involved in theory of mind processes, are more active when people mimic the pupil sizes of an observed other, compared with when they do not (Prochazkova et al., 2018).

During eye-contact, the pupil sizes of individuals tend to synchronize so that dilating pupils induce pupil dilation in the partner, and constricting pupils increase pupil constriction in the partner (Harrison, Singer, Rotshtein, Dolan, & Critchley, 2006). Pupil mimicry is already present during the first months of life (Fawcett, Wesevich, & Gredebäck, 2016; Zhu, Checkley, Hickey, & Isherwood, 1986) and is an evolutionary old phenomenon shared with chimpanzees (Kret et al., 2014). Pupil mimicry in humans relates to intuitive assessments of a partner's trustworthiness (Kret et al., 2015). In an experiment, Dutch participants played trust games with partners of whom just the eye region was visible and in which the pupils were manipulated to change in size. The results showed that participants' pupils dilated synchronously with their partner's pupils. Importantly, this correlated with levels of trust, especially when partners were Dutch too. A second study confirmed that intuitive decisions to trust are influenced by mimicry and group membership of the partner, that both oxytocin and sex of participant and partner further moderated these effects, and that these effects could not be explained by different looking patterns or attention (Kret & De Dreu, 2017).

These results suggest that in a safe environment with similar others, the dilating pupils of an interaction partner may unconsciously communicate positive attention and social interest. By automatically mimicking that reaction, emotional states may converge (Hatfield, Cacioppo, & Rapson, 1993) and a person's own pupils may provide internal feedback, influencing how the other is perceived (Prochazkova & Kret, 2017). Support for this theory comes from a study where participants, in the context of a personnel selection scenario, judged the attentiveness of people appearing in photographs. Images of faces with large pupils were judged as more attentive, compared with images of faces with small pupils (Watier, Healy, & Armstron, 2016). A recent study by Kang and Wheatley (2017) tested whether pupil mimicry is an implicit corollary of shared attention. In that study, speakers were videotaped and eye-tracked as they discussed emotional autobiographical memories. An independent group of listeners were then eye-tracked while watching these videos. The pupil sizes of speakers and listeners were measured and the emotional salience of each narrative was assessed by independent raters. The results show that pupil mimicry between speakers and listeners was greatest during the emotional peaks of a narrative. Pupillary fluctuations can thus be an index of perceived attention (i.e., the other finds me interesting), possibly explaining why dilated and dilating pupils are perceived positively.

It is possible that the positive effect that people get from looking into the eyes of someone with large pupils is the result of an empathic process that fosters mimicry. In an earlier study by Harrison, Wilson, and Critchley (2007), it was found that sadness was perceived more intensely when the models had small pupils. The degree to which pupil size influenced sadness processing correlated with individual differences in empathy. Furthermore, neuroimaging studies provide supporting evidence for action—perception models of empathy by showing shared neural activation when experiencing, for instance, touch (Blakemore, Bristow, Bird, Frith, & Ward, 2005; Keysers et al., 2004), disgust (Wicker, Keysers, Plailly, Royet, Gallese, & Rizzolatti, 2003) and pain (Morrison, Lloyd, di Pellegrino, & Roberts, 2004; Singer et al., 2004; Jackson, Meltzoff, & Decety, 2005) in oneself and when perceiving this when observing others. Common neuronal networks are also activated when subjects imitate or observe different emotional facial expressions (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003), and, as we recently showed, during pupil mimicry (Prochazkova et al., 2018). Future research might focus on the possible effects of empathy on these phenomena. While doing that, particular attention should be paid to a possible confounding effect of attention. Perhaps, empathic people pay more attention to others and therefore mimic or perceive subtle cues better. The effect of attention was also demonstrated in an fMRI study. In the experiment, participants observed an interaction between an aggressor and a victim. Specifically, when asked to attend to the victim (and not the aggressor), empathy predicted the extent of activation in areas well known for processing emotions (van den Stock et al., 2015).

Our study has several limitations. First, in Experiment 1 we used several partner evaluation measures that are likely to be highly correlated. A partner that appears friendlier is very likely to be trusted better. Although this will be impossible to prevent, in future experiments, it would be interesting to include negative personality traits as well, so that participants evaluate their virtual partners on measures of distrust or unkindness. Another important point to note here is that in the experiments presented here, the pupils of partners changed dynamically and that this was noticeable to participants. It is not clear whether similar results would have been obtained had we presented static pupils, although previous works that did use static pupillary manipulations (e.g., Demos et al., 2008; Harrison et al., 2006; Hess, 1975) suggest similar results would have been found. Still, future research should investigate this issue further. Another limitation is that in Experiment 3, the eyes that were to be ignored were presented next to a target face, and not in the middle of the screen, so this means that the effects are not completely comparable with Experiments 1 and 2. The inspection of the means (see Table 2) shows that the pattern is very different from that observed in Experiment 1 and 2. If the results could be explained by a weaker experimental manipulation, dampened effects are expected that hint toward the same direction as the previous experiments. Still, it is important to consider that the eyes were presented parafoveally, and we do not know whether the pupillary changes were perceived equally well as in the previous two studies. Participants were free to make eye movements as they wished, but these were not recorded, so we are unsure whether they did. Comparing whether central, as opposed to parafoveal presentation alters pupillary information processing, needs to be investigated in future studies. Other research has shown that the visual processing of ecologically relevant stimuli involves a central bias for stimuli demanding detailed processing (e.g., faces), whereas peripheral processing is based on coarse identification. The almost immediate detection of animal shapes holding a significant phylogenetic value, such as predators, benefits from peripheral vision, allowing us to act quickly (Almeida, Soares, & Castelo-Branco, 2015). Eyes are very powerful stimuli and are known to attract attention from an early age (Farroni et al., 2002). It is therefore unlikely that our participants missed the eyes and the changes in pupil size, even though they were presented in the periphery.

In our daily interactions, humans tend to make a lot of eye-contact and by doing so, infer important social information about the emotions and intentions of others emotions and intentions. Our eyes are relatively large compared with other species, and with the eye-white surrounding the iris, they pull attention to the middle part, to the pupil. Although the pupil is very small and its size or dynamic changes in size in real life situations are prone to ambient light, we believe that the current study underlines the importance of further studying this subtle physiological cue that influences human social behavior. Making eye contact and exchanging pupillary information might have important implications in real life decision making such as to trust a partner and cooperate, or to refrain from doing so. It is possible that such decisions are better informed by implicit cues of pupil size, allowing for fast and intuitive transmission of this subtle social information.

Table 2
Experiment 3

Observer gaze direction	Observer pupil size	*M*	*SE*
Gaze at partner/trustee (to side)	Constricting	2.124	.198
	Static	2.208	.196
	Dilating	2.042	.214
Gaze at participant (direct)	Constricting	2.292	.221
	Static	2.151	.200
	Dilating	2.032	.219

Note. M = predicted mean; SE = standard error.

Context of the Research

Mariska E. Kret's first investigation into mimicry focused on facial mimicry, and facial expressions following the perception of emotional body language (Kret, Roelofs, et al., 2013; Kret, Stekelenburg, et al., 2013). Working with great apes sparked her interest in the human eye and its role in communication. Comparing humans and chimpanzees, she observed that people mimic the pupil sizes of people, and chimpanzees predominantly of chimpanzees (Kret et al., 2014). This within-species effect motivated her to investigate the function of pupil mimicry in collaboration with her former postdoctoral supervisor Carsten K. W. De Dreu, expert in behavioral economics (Kret, Fischer, & de Dreu, 2015). Why do people mimic and is this related to the fact that others with large pupils are generally perceived positively (e.g., Amemiya & Ohtomo, 2012; Brambilla et al., 2018; Hess, 1975)? Mariska E. Kret and her doctoral-level student Prochazkova developed a neurocognitive model of emotional contagion (Prochazkova & Kret, 2017) to provide a theoretical framework for a range of mimicry or synchronization forms that in real life are occurring simultaneously. Together with PhD student Friederike Behrens she investigates pupil mimicry and other forms of autonomic mimicry during dyadic interactions in the lab. PhD student Katharina Wehebrink studies similar phenomena in a clinical setting (Wehebrink et al., 2018). A future aim is to investigate a range of emotional expressions and their mimicry during dyadic interactions in different real life situations. But alongside that research, it is important to invest in research with the aim to fully understand the effects of underinvestigated expressions such as pupil size and the contextual boundaries of such effects. The current work is a step into that direction.

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