All that meets the eye: the contribution of reward processing and pupil mimicry on pupillary reactions to facial trustworthiness

Frisanco, A.; Biella, M.; Brambilla, M.; Kret, M.E.

Current Psychology
https://doi.org/10.1007/s12144-021-02486-w

All that meets the eye: The contribution of reward processing and pupil mimicry on pupillary reactions to facial trustworthiness

Althea Frisanco[1,2,3] · Marco Biella[4] · Marco Brambilla[5] · Mariska E. Kret[6]

Accepted: 4 November 2021

Abstract
The present work investigates pupillary reactions induced by exposure to faces with different levels of trustworthiness. Participants' (N = 69) pupillary changes were recorded while they viewed white male faces with a neutral expression varying on facial trustworthiness. Results suggest that reward processing and pupil mimicry are relevant mechanisms driving participants' pupil reactions. However, when including both factors in one statistical model, pupil mimicry seems to be a stronger predictor than reward processing of participants' pupil dilation. Results are discussed in light of pupillometry evidence.

Keywords Pupillometry · Trustworthiness · Social perception · Eye-tracking · Face perception

Evaluating whether people around us represent a threat for our own safety or, conversely, opportunities for friendly interactions, is a daily fundamental challenge with major implications for survival in social environments. Since we cannot access others' intentions directly, we base the first impression of others on readily available cues, among which facial appearance plays a key role (Ro et al., 2001; Theeuwes & Van der Stigchel, 2006; Zebrowitz, 1997). People process facial features quickly (Stewart et al., 2012; Willis & Todorov, 2006) and infer a wide range of information with a different degree of confidence and accuracy. For instance, sex, age and race are immediately perceived because their physical markers tend to be perceptually obvious (Bruce & Young, 2012). Other characteristics such as political orientation, social class or sexual orientation are more difficult to infer as they are perceptually ambiguous (Alaei & Rule, 2016; Rule et al., 2015; Tskhay & Rule, 2013). People also draw conclusions about others' personality characteristics such as competence and trustworthiness based on facial appearance (Hassin & Trope, 2000; Todorov et al., 2015; Zebrowitz & Montepare, 2008).Trustworthiness evaluation is one of the most relevant processes among face-based inferences (Oosterhof & Todorov, 2008) due to the evolutionary importance of threat detection (Brambilla et al., 2018, 2019b, 2021). Indeed, facial trustworthiness and threat are linked such that untrustworthy and trustworthy faces are perceived as threatening and beneficial, respectively. Thus, trustworthiness evaluation is made spontaneously (Klapper et al., 2016) after as little as 33 ms of exposure to a face (Todorov et al., 2009) and it highly correlates with overall facial evaluation (Oosterhof & Todorov, 2008). Moreover, such a quick evaluation of facial trustworthiness influences subsequent approach or avoidance behaviors (Slepian et al., 2012) and a number of other social outcomes such as personnel selection, voting behavior and economic exchange (Duarte et al., 2012; Olivola et al., 2014). Facial trustworthiness also influences penalty impositions and death sentences despite the questionable accuracy of trustworthiness assumptions (Porter, ten Brinke, & Gustaw, 2010; Wilson & Rule, 2015, 2016).

✉ Althea Frisanco
althea.frisanco@uniroma1.it

1 Department of Psychology, Sapienza University of Rome, "Sapienza", Via dei Marsi, 78, 00185 Rome, Italy

2 Center for Life Nano Science, Italian Institute of Technology, Rome, Italy

3 IRCCS Santa Lucia Foundation, Rome, Italy

4 Psychology Department, Eberhard Karls Universität Tübingen, Tübingen, Germany

5 Department of Psychology, University of Milano - Bicocca, Milan, Italy

6 Cognitive Psychology Unit, Institute of Psychology, Leiden University, Leiden, The Netherlands

Published online: 09 November 2021

Over time, physiological and brain reactions to facial trustworthiness have caught the attention of researchers and several approaches have been used to study physiological and neural changes in response to trustworthy and untrustworthy faces (e.g., Dzhelyova et al., 2012; Freeman et al., 2014; Jessen & Grossmann, 2019; Sakuta et al., 2018; Santos et al., 2016; Vecchiato et al., 2014). However, pupil reactions to facial trustworthiness are still largely unexplored even if facial trustworthiness seems to be the most relevant dimension in face perception (Todorov et al., 2008). Thus, here we aim at testing how such a relevant dimension and pupil size relate. The belief that light intensity is solely responsible for pupil changes has since long known to be false, supporting the notion that cognitive and affective states can induce changes in pupil size (Andreassi, 2000). Pupil size reflects arousal and is an index of norepinephrine levels in the brain. As arousal is blind to valence, pupil size can reflect negative arousal, but also positive arousal (e.g., Chiew & Braver, 2014; Kret et al., 2013). Increases in pupil size have also been related to two distinct temporal components characterizing reward processing: dilations have been recorded during both the anticipation of a rewarding stimulus as well as during the reward presentation (Bijleveld et al., 2009; Chiew & Braver, 2013; Kostandyan et al., 2018; Massar et al., 2018; Rudebeck et al., 2014; Schneider et al., 2018). Thus, considering that the pupil also dilates as a consequence of reward processing, we expect that facial trustworthiness triggers the very same physiological outcome. Indeed, two recent meta-analyses have clearly demonstrated trustworthiness' rewarding nature (Mende-Siedlecki et al., 2013; Santos et al., 2016), due to the emotion overgeneralization which makes trustworthy faces resemble happy expressions (Oosterhoff & Todorov, 2009) and, as such, links them to the reward system just as a happy expression would (Seidel et al., 2010; Todorov, 2008).

Another potential mechanism underlying pupil dilation may be pupil mimicry. When looking into the dilating pupils of an interaction partner, chances are high that ones' own pupils start to dilate, too. Pupil mimicry -namely the process in which the perceiver's pupil size unconsciously mimics the partner's pupil size- might affect pupil reactions independently of the partners' trustworthiness. Pupil mimicry, also dubbed pupillary contagion, has been shown in human adults (Carsten et al., 2019; Harrison et al., 2006), infants (Aktar et al., 2020; Fawcett et al., 2016) and chimpanzees (Kret, Tomonaga & Matsuzawa, 2014). Although it is largely an unconscious phenomenon that works outside of our awareness, it is not insensitive to contextual factors. For example, it works particularly well between members of the same species (Kret, Tomonaga & Matsuzawa, 2014), is influenced by group membership (Kret, Fischer & de Dreu, 2016; Derksen et al., 2018, but see Aktar et al., 2018), by interaction context (van Breen et al., 2018) and breaks down when looking at squared versus round pupils (Fawcett et al., 2017; Hess, 1975). Pupil mimicry is a disputed phenomenon and the evidence of its occurrence and significance are mixed (e.g., Derksen et al., 2018; Mathôt & Naber, 2018; see also Mattavelli et al., in press), For instance, it has been argued that pupil mimicry reflects, at least in part, a pupil light response. Indeed, some studies reveal that pupil mimicry did not emerge when static images equalized for luminance are taken into account. Rather, in line with the idea that pupil mimicry would be the result of brightness perception, pupil mimicry would emerge only when salient, dynamic stimuli that attract enough attention to the luminance in the eye region are taken into account (Derksen et al., 2018). Thus, some works suggest that pupil mimicry is not seem a social phenomenon as it seems to be an artefact induced by light response (see Derksen et al, 2018). In sharp contrast, other studies show a consistence emergence of pupil mimicry in social interactions that may help partners to take each other perspective more readily, guiding social decisions such as to trust someone or not (Kret & de Dreu, 2017; Kret, et al., 2015; Prochazkova et al., 2018b). Thus, pupil mimicry seems an area of investigation that needs to be investigated more in depth in order to capture its emergence and (more importantly) the underlying mechanisms. Nevertheless, research suggests that pupil mimicry may be responsible for making the partner appear more similar, and therefore more trustworthy in the eyes of the observers. Indeed, although several facial traits increase trustworthiness -such as wide chins, high inner margins of the eyebrows, pronounced cheekbones and shallow nose sellion (Todorov et al., 2008)- the eye region is found to be especially attractive and salient starting from early infancy (Farroni et al., 2002), so much so that people continuously make eye-contact to probe other's inner states and intentions (Kret, 2015; Prochazkova & Kret, 2017; Senju & Johnson, 2009). In a pioneering work by Hess (1965), he demonstrated that images depicting women with large pupils are preferred to women with small ones (see also Kret, 2018). Latest developments expanded such insight proving that people ascribe positive traits -including trustworthiness- to partners with dilated pupils (Kret & De Dreu, 2017; Kret et al., 2015; Van Breen et al., 2018; Weibel et al., 2010).

Thus, reward processing and pupil mimicry might be two mechanisms that could trigger pupil dilation. On the one hand, trustworthy faces are expected to increase participants' pupil size through their inherent reward value; on the other hand, observers' pupil size is expected to unconsciously mimic partners' pupil size, regardless of partners' trustworthiness.

Experiment

Participants and Sample Size Justification

Considering the lack of previous literature on the use of pupillometry in investigating trustworthiness perception, effect size estimations needed for an a-priori power analysis are missing. Therefore, we relied on a sample size from previous pupillometry studies. We took a previous work from Kret, Fischer and De Dreu as a benchmark (Kret et al., 2015), in which 69 participants were enrolled. The current study included the same number of participants (46 female, 23 male; Mage = 22.62 years, SDage = 4.6, range = 18–57). It is worth noting that, compared to the benchmark experiment, our study has a simpler experimental design with fewer within-subjects conditions. The study was approved by the local ethics committee and was conducted according to the guidelines that were established in the Declaration of Helsinki.

Methods

Procedure

Upon arrival, participants were informed about the task they were about to perform and provided written informed consent. The experiment was run in a dim, quiet room where participants were seated in front of the computer with their head placed on a chinrest at 60 cm from the screen. Stimuli were displayed using E-Prime software (Psychology Software Tools, Pittsburgh, PA) and pupil size measures were taken using an EyeLink1000 eye-tracker at a 1000 Hz sampling rate, which returns pupil diameter as arbitrary units, (i.e., an integer number) (see the Eyelink 1000 User manual, SR Research Ltd., 2009). A 5-point calibration has been performed before recording.

The task was a simple passive viewing task in which participants were asked to look at the screen. Every trial was composed of two images, a mask presented for 750 ms and the stimulus face (Fig. 1) presented for 5000 ms. For every stimulus, a different mask was generated by scrambling the pixels of the very same stimulus in order to match its luminance. The mask was introduced to limit the pupillary light reflex. By presenting light-matched masks, we allowed the eye to calibrate pupil dilation to the light coming from the screen so that when the stimulus appeared, pupil dilation due to light conditions was minimized. After the stimulus presentation, a blank screen was presented for 500 ms to separate different trials.

Materials

The stimuli presented were faces from the Chicago Face Database (Ma et al., 2015) with a manually cropped background such that only the neck, face, and hair were visible. We selected only white male stimuli with a neutral expression in order to keep the experimental design as simple as possible. In total we employed 93 stimuli. All stimuli were previously rated by 1087 independent raters, along several perception dimensions on a 1–7 Likert scale (1 = Not at all, 7 = Extremely) (see, Ma et al., 2015). By aggregating the average rating for each stimulus, this procedure provided normative trustworthiness rating ranging from 2.31 to 3.92 ($M = 3.21$, $SD = 0.34$) in our subset of face stimuli (Fig. 2).

Results

Preliminary Analysis: Data Preparation

Pupil diameter was sampled with a rate of 1000 Hz per eye and was later down-sampled to 100-ms time slots. Gaps smaller than 250 ms were interpolated, and a 10th-order low-pass Butterworth filter was used to smooth the data in the PhysioData Toolbox v0.3.5 (Kret & Sjak-Shie, 2019). If the pupil sizes from two subsequent time points exceeded two standard deviations from the mean change between two subsequent datapoint (which is for instance the case with a spike), those datapoints were excluded from the analysis (Kret & Sjak-Shie, 2019). For each trial, we averaged 500 ms prior to stimulus onset,

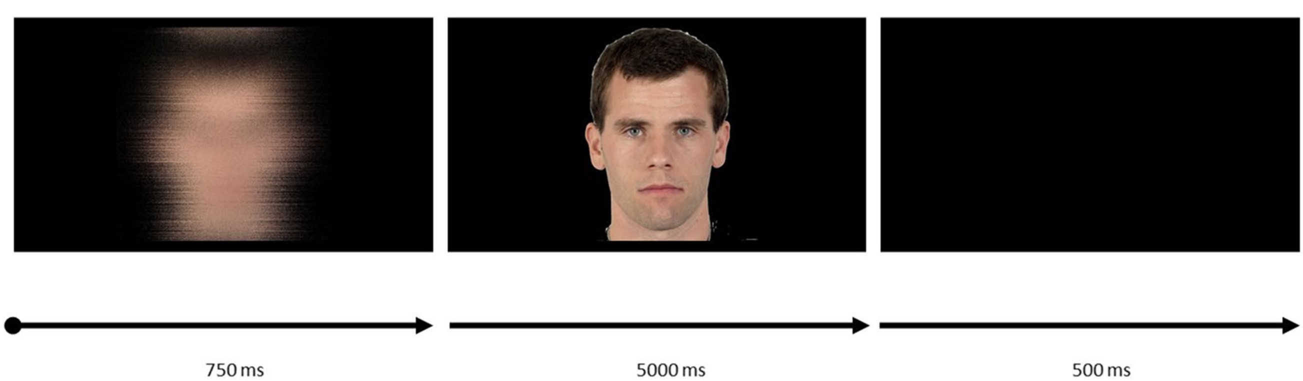

Fig. 1 A visual representation of an experimental trial

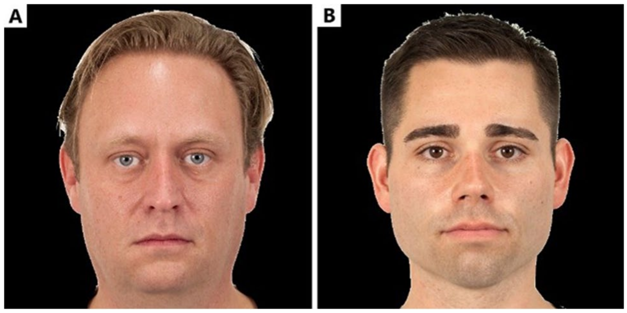

Fig. 2 Examples of (**A**) untrustworthy and (**B**) trustworthy faces

which served as a baseline measure. Pupil responses were then expressed as differences from baseline by subtracting the mean baseline pupillary diameter from all subsequent samples. Following standard procedures, the first 2 secs after stimulus onset were discarded from the analysis (Bradley et al., 2008).

The data was analyzed in a general linear mixed multilevel model with trials nested within participants. A random intercept for participant was added.

Main Analysis

A general linear mixed model with normative trustworthiness, as fixed factor and pupil size as dependent variable, showed that the more trustworthy the observed face, the larger participants' pupil size F(1.197,595) = 4.623, p = 0.032 (Fig. 3A). This analytical procedure was preferred to properly model the multilevel structure of our data presenting multiple observations for every subject, which we included as a random factor (Robinson, 1991).

In a subsequent analysis, we investigated whether the pupil size of the stimulus face influenced participants' pupil size. As expected, the larger the size of the stimulus pupils, the larger participants' own pupils F(1.197,595) = 5.812, p = 0.016 (Fig. 3B). Possibly, the stimulus materials with larger pupil sizes had lower luminance levels and as a consequence caused participants' pupils to dilate. In order to rule out this alternative explanation, we ran a correlational analysis between stimulus' pupil size and stimulus' luminance. The result of this test was not significant, r(91) = -0.052, p = 0.618, suggesting thus that the effect of stimulus' pupil size on participants' pupil size was not driven by luminance. Moreover, we excluded that trustworthy stimuli's luminance did cause participants' pupils dilation as those stimuli were not brighter than untrustworthy ones. Indeed, we found no significant correlation between trustworthiness and luminance r(91) = -0.0967, p = 0.356.

Previous work has shown that large pupils in an observed other make observers trust that person better (Brambilla et al. 2019a; Kret & De Dreu, 2017; Kret et al., 2015; Prochazkova et al., 2018a, b). In order to investigate whether this was also the case in the current study, we ran a Pearson correlation between stimulus' pupil size and normative trustworthiness, which showed a trend towards significance in the expected direction r(91) = 0.200, p = 0.055 (Table 1).

This correlation was weak enough to allow us to include both factors in a general linear mixed model to predict participants' pupil size again, without risking multicollinearity issues. Thus, we ran this model with both trustworthiness and stimulus' pupil size included as fixed factors and observed that stimulus' pupil size remained a significant predictor of participants' pupil size F(1.197,595) = 4.099, p = 0.043, while trustworthiness showed a trend towards significance F(1.197,595) = 2.910, p = 0.088.

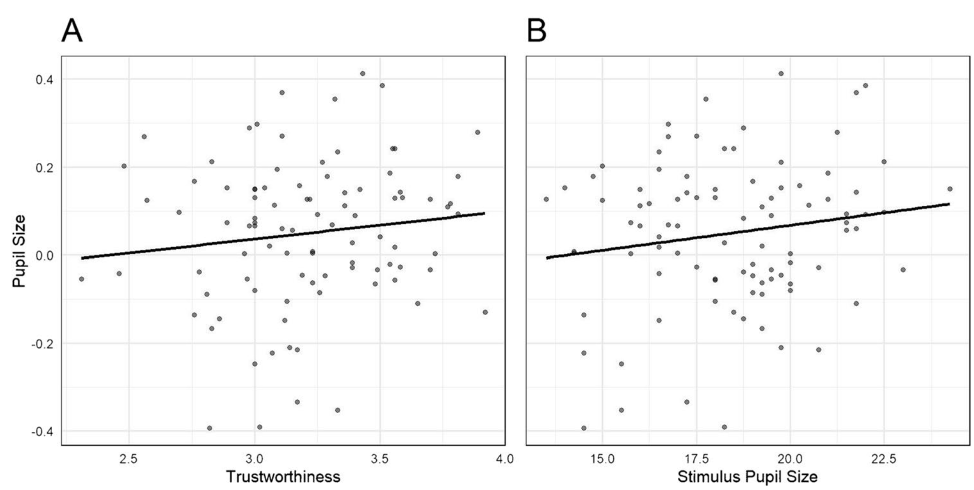

Fig. 3 Participants' average pupil's reaction as function of (**A**) stimulus' trustworthiness, and (**B**) stimulus' pupil size

Table 1 Correlation matrix reporting correlations (lower diagonal) and p-values (upper diagonal) among stimulus features and participant's pupillary reactions. Relationships involving participant's pupillary reactions (marked with *) were computed relying on multi-level repeated measures correlations to avoid averaging and violating the observations' independence assumption

	Trustworthiness	Pupil	Pupil (participant)	Luminance
Trustworthiness		.055	.041*	.36
Pupil	.20		< .0001*	.62
Pupil (participant)	.03*	.07*		< .0001*
Luminance	-.10	-.05	-.17*	

General Discussion

The current study aimed at integrating research on pupil dilation with that on how facial trustworthiness is processed; indeed, we tested how participants' pupils react to trustworthy and untrustworthy faces. In doing so, we displayed the whole face stimulus without any manipulation of facial features, pupil size included. Thus, we did not compromise the database's ecological validity, specifically on the trustworthiness dimension. In doing so, we focused on the trustworthiness dimension as it is considered the primary dimension of face perception in functional terms (Todorov, 2008; Todorov et al., 2009, 2015) and therefore, the one theoretically most likely to inform post-perception decisions and behaviors. However, to preserve the ecological value of our stimuli set, we could not control or balance the natural variation of other traits that may drive participants' reactions to the stimuli and may correlate or co-occur with trustworthiness (Ma et al., 2015).

In short, among the many facial features which determine the impression, pupil size represents a readily available cue which is unconsciously processed during interactions (e.g., Brambilla et al., 2019a). As a result, partners with large pupils are preferred to partners with small ones (Hess, 1965) to the extent that people ascribe positive traits -including trustworthiness- to partners with dilated pupils and negative attributes -including untrustworthiness- to those with constricted pupils (Kret & De Dreu, 2017; Kret et al., 2015). Thus, it is reasonable to assume that the pupil size of each stimulus we adopted in the present work affected the trustworthiness evaluation during the validation of the database, as much as any other dimension rated.

Our early analysis were consistent with our expectations. In fact, the results suggested a positive relationship between trustworthy targets and participants' pupil dilations. The more trustworthy the stimulus, the more participants' pupils dilated after seeing it, supporting the literature on the rewarding nature of trustworthy faces and their potential in evoking positive arousal. However, this turned out not to be the complete story. A subsequent analysis, aimed to investigate pupil mimicry, has yielded a more comprehensive and complex framework. In fact, after controlling for the stimulus-related pupil size, it seems that this variable may even better explain the perceiver's pupil reactions.

Recently, the adaptive function of pupil mimicry has received a growing amount of attention. Indeed, it has been suggested that pupil mimicry might contribute to promoting swift communication of inner states and in making shared understanding easy (Kret et al., 2014), an adaptive process that, in turn, would lead to remarkable social outcomes. For instance, among the consequences on social interactions, fostering trust is a well-known result widely reported (e.g., Kret & de Dreu, 2017; Kret et al., 2015), which adds to overall effects of interpersonal mimicry (e.g., increasing affiliation and liking, reducing prejudice) (Hove & Risen, 2009; Inzlicht et al., 2012; Lakin et al., 2003). Thus, feeling the reflection of the inner states of others, might be the means through which mimicry leads to trust formation and affiliation. This hypothesis was explored by Prochazkova et al., (2018a, 2018b), whose neuroimaging study showed that pupil mimicry was associated with increased activation of the Theory of Mind network (ToM; Saxe & Wexler, 2005; Schaafsma et al., 2015), the well-known system supporting social understanding (Saxe & Wexler, 2005; Schurz et al., 2014). Interestingly, the authors pointed out that pupil mimicry activated a neural pattern similar to those observed during explicit forms of mirroring implicated in social cognition (e.g., Rizzolatti & Sinigaglia, 2016), strengthening the assumption that others' behavioral intentions may also be inferred through pupil mimicry. Our findings seem to support and extend previous pupil mimicry research by showing that such mechanism could be also present in a face perception scenario, where the partners' whole face is available with naturally occurring pupil sizes. Indeed, previous studies focusing on pupil mimicry have usually cropped images to only show the eye region or manipulated partners' pupil size (e.g., Kret et al., 2015; Prochazkova et al., 2018a, b) and thus our work might represent a further confirmation in a more natural scenario.

To conclude, our analysis suggests that both reward processing and pupil mimicry are significant mechanisms driving participants' pupil reactions. However, among the two, pupil mimicry seems to be the strongest predictor when we include the two of them in one statistical model. Importantly, considering that stimulus' pupil size and normative trustworthiness show very little correlation -although the correlation was weak enough to allow our analysis- further investigation are required. Specifically, future developments might manipulate stimulus pupil size and stimulus facial trustworthiness independently to pull apart their independent effects on person perception and pupillary reactions. In this work, we consciously opted for a simple design to achieve the study's purposes, as a pupil size manipulation would have necessarily meant questioning how faces would have been perceived along the trustworthiness dimension, compromising the database validity.

In addition, future works might shed some light on the time course of pupil dilation. The first 2 secs after stimulus onset have been discarded following standard procedures (Bradley et al., 2008) and our investigation was more focused on the trial level than the continuous fluctuation of pupil size. Future developments could fill the gap by investigating the divergence of pupil dilation over time as a function of the displayed stimuli, or during real life dyadic interactions. While pupil mimicry seems to mostly explain the results of our experiment, different time sensitive mechanisms might be implicated. For example, combining research suggesting arousal-evoking nature of untrustworthy faces (Aguado et al., 2011) and emotional arousal influence on pupil reactions (Bradley et al., 2008), one can wonder if untrustworthy stimuli and their potential fear-evoking nature- might affect observers' pupil dilation in earlier stages of the pupil track. Such an effect clearly did not occur in the time window we analyzed and, consistent with the hypothesis, positive arousal and pupil mimicry prevailed. However, we must consider that perhaps our stimuli may have not been perceived threatening enough. Thus, future research could investigate pupillary fluctuation over time to point out any impact on pupil size of other mechanisms in different stages.

Further investigations should also investigate the pattern of results we reported by including a wider range of facial stimuli. Due to the necessity to keep the experimental design as simple as possible, we settled on pictures depicting only white men. Thus, further studies may consider how gender or social categorization (ingroup vs. outgroup faces; Birkás et al., 2014) may moderate the results we found. Despite these limitations, our study reached the goal of enriching the literature on trustworthiness perception by using pupillometry analysis and providing a unique and highly ecological setting in which implications and overlaps of several mechanisms on social perception and physiological outcomes are discussed comprehensively.

Declarations

Conflict of Interest The authors have no conflict of interest to disclose.

Ethical Approval The study presented in the manuscript has been carried out in accordance with the ethical standards of the APA. Data and open materials are available on the Open Science Framework at the following link https://osf.io/s3z5k/. The used stimuli are not available as Terms of Use of the Chicago Face Database (Ma et al., 2015) prohibit redistribution.

References

Aguado, L., Román, F. J., Fernández-Cahill, M., Diéguez-Risco, T., & Romero-Ferreiro, V. (2011). Learning about faces: Effects of trustworthiness on affective evaluation. *The Spanish Journal of Psychology, 14*(2), 523–534.

Aktar, E., Majdandžić, M., De Vente, W., & Bögels, S. M. (2018). Parental expressions of anxiety and child temperament in toddlerhood jointly predict preschoolers' avoidance of novelty. *Journal of Clinical Child & Adolescent Psychology, 47*(sup1), S421–S434.

Aktar, E., Raijmakers, M. E., & Kret, M. E. (2020). Pupil mimicry in infants and parents. *Cognition and Emotion, 34*(6), 1160–1170.

Alaei, R., & Rule, N. O. (2016). Accuracy of perceiving social attributes. In J. A. Hall, M. Schmid Mast, & T. V. West (Eds.). *The social psychology of perceiving others accurately* (pp. 125–142). Cambridge University Press. https://doi.org/10.1017/cbo9781316181959.006.

Andreassi, J.L, (2000). Chap. 10, Pupillary response and behavior. In: Psychophysiology: Human Behavior & Physiological Response, *4th ed.* Lawrence Erlbaum Assoc., Mahwah, N.J., pp. 218–233.

Bijleveld, E., Custers, R., & Aarts, H. (2009). The unconscious eye opener: Pupil dilation reveals strategic recruitment of resources upon presentation of subliminal reward cues. *Psychological Science, 20*(11), 1313–1315. https://doi.org/10.1111/j.1467-9280.2009.02443.x

Birkás, B., Dzhelyova, M., Lábadi, B., Bereczkei, T., & Perrett, D. I. (2014). Cross-cultural perception of trustworthiness: The effect of ethnicity features on evaluation of faces' observed trustworthiness across four samples. *Personality and Individual Differences, 69*, 56–61.

Bradley, M. M., Miccoli, L., Escrig, M. A., & Lang, P. J. (2008). The pupil as a measure of emotional arousal and autonomic activation. *Psychophysiology, 45*(4), 602–607. https://doi.org/10.1111/j.1469-8986.2008.00654.x

Brambilla, M., Biella, M., & Freeman, J.B. (2018). The influence of visual context on the evaluation of facial trustworthiness. *Journal of Experimental Social Psychology, 78*, 34–42.

Brambilla, M., Biella, M., & Kret, M. E. (2019a). Looking into your eyes: Observed pupil size influences approach-avoidance responses. *Cognition and Emotion, 33*(3), 616–622.

Brambilla, M., Carraro, L., Castelli, L., & Sacchi, S. (2019b). Changing impressions: Moral character dominates impression updating. *Journal of Experimental Social Psychology, 82*, 64–73.

Brambilla, M., Sacchi, S., Rusconi, P., & Goodwin, G. (2021). The primacy of morality in impression development: Theory, research, and future directions. *Advances in Experimental Social Psychology, 64*, 187–262.

Bruce, V., & Young, A. (2012). *Face perception*. Psychology Press.
Carsten, T., Desmet, C., Krebs, R. M., & Brass, M. (2019). Pupillary contagion is independent of the emotional expression of the face. *Emotion, 19*(8), 1343.
Chiew, K. S., & Braver, T. S. (2013). Temporal dynamics of motivation-cognitive control interactions revealed by high-resolution pupillometry. *Frontiers in Psychology, 4*, 15.
Chiew, K. S., & Braver, T. S. (2014). Dissociable influences of reward motivation and positive emotion on cognitive control. *Cognitive, Affective, & Behavioral Neuroscience, 14*(2), 509–529.
Derksen, M., van Alphen, J., Schaap, S., Mathot, S., & Naber, M. (2018). Pupil mimicry is the result of brightness perception of the iris and pupil. *Journal of cognition, 1*(1).
Duarte, J., Siegel, S., & Young, L. (2012). Trust and credit: The role of appearance in peer-to-peer lending. *The Review of Financial Studies, 25*(8), 2455–2484.
Dzhelyova, M., Perrett, D. I., & Jentzsch, I. (2012). Temporal dynamics of trustworthiness perception. *Brain Research, 1435*, 81–90.
Farroni, T., Csibra, G., Simion, F., & Johnson, M. H. (2002). Eye contact detection in humans from birth. *Proceedings of the National Academy of Sciences, 99*(14), 9602–9605.
Fawcett, C., Arslan, M., Falck-Ytter, T., Roeyers, H., & Gredebäck, G. (2017). Human eyes with dilated pupils induce pupillary contagion in infants. *Scientific Reports, 7*(1), 1–7.
Fawcett, C., Wesevich, V., & Gredebäck, G. (2016). Pupillary contagion in infancy: Evidence for spontaneous transfer of arousal. *Psychological Science, 27*(7), 997–1003.
Freeman, J. B., Stolier, R. M., Ingbretsen, Z. A., & Hehman, E. A. (2014). Amygdala responsivity to high-level social information from unseen faces. *Journal of Neuroscience, 34*(32), 10573–10581. https://doi.org/10.1523/JNEUROSCI.5063-13.2014
Harrison, N. A., Singer, T., Rotshtein, P., Dolan, R. J., & Critchley, H. D. (2006). Pupillary contagion: Central mechanisms engaged in sadness processing. *Social Cognitive and Affective Neuroscience, 1*(1), 5–17.
Hassin, R., & Trope, Y. (2000). Facing faces: Studies on the cognitive aspects of physiognomy. *Journal of Personality and Social Psychology, 78*, 837–852.
Hess, E. H. (1965). Attitude and pupil size. *Scientific American, 212*(4), 46–55.
Hess, E. H. (1975). The role of pupil size in communication. *Scientific American, 233*(5), 110–119.
Hove, M. J., & Risen, J. L. (2009). It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition, 27*(6), 949–960. https://doi.org/10.1521/soco.2009.27.6.949
Inzlicht, M., Gutsell, J. N., & Legault, L. (2012). Mimicry reduces racial prejudice. *Journal of Experimental Social Psychology, 48*(1), 361–365.
Jessen, S., & Grossmann, T. (2019). Neural evidence for the subliminal processing of facial trustworthiness in infancy. *Neuropsychologia, 126*, 46–53.
Klapper, A., Dotsch, R., van Rooij, I., & Wigboldus, D. H. (2016). Do we spontaneously form stable trustworthiness impressions from facial appearance? *Journal of Personality and Social Psychology, 111*(5), 655.
Kostandyan, M., Bombeke, K., Carsten, T., Krebs, R. M., Notebaert, W., & Boehler, C. N. (2018). Differential effects of sustained and transient effort triggered by reward: A combined EEG and pupillometry study. *Neuropsychologia*. Advanced online publication. https://doi.org/10.1016/j.neuropsychologia.2018.04.032
Kret, M. E. (2015). Emotional expressions beyond facial muscle actions. A call for studying autonomic signals and their impact on social perception. *Frontiers in psychology*, *6*, 711.
Kret, M. E. (2018). The role of pupil size in communication. Is there room for learning?. *Cognition and Emotion*, *32*(5), 1139–1145.
Kret, M. E., Fischer, A. H., & De Dreu, C. K. (2015). Pupil mimicry correlates with trust in in-group partners with dilating pupils. *Psychological Science, 26*(9), 1401–1410. https://doi.org/10.1177/0956797615588306
Kret, M. E., & De Dreu, C. K. (2017). Pupil-mimicry conditions trust in partners: Moderation by oxytocin and group membership. *Proceedings of the Royal Society b: Biological Sciences, 284*(1850), 20162554. https://doi.org/10.1098/rspb.2016.2554
Kret, M. E., & Sjak-Shie, E. E. (2019). Preprocessing pupil size data: Guidelines and code. *Behavior Research Methods, 51*(3), 1336–1342. https://doi.org/10.3758/s13428-018-1075-y
Kret, M., Stekelenburg, J., Roelofs, K., & De Gelder, B. (2013). Perception of face and body expressions using electromyography, pupillometry and gaze measures. *Frontiers in Psychology, 4*, 28.
Kret, M. E., Tomonaga, M., & Matsuzawa, T. (2014). Chimpanzees and humans mimic pupil-size of conspecifics. *PLoS One*, *9*(8), e104886.
Lakin, J. L., Jefferis, V. E., Cheng, C. M., & Chartrand, T. L. (2003). The chameleon effect as social glue: Evidence for the evolutionary significance of nonconscious mimicry. *Journal of Nonverbal Behavior, 27*(3), 145–162.
Ma, D. S., Correll, J., & Wittenbrink, B. (2015). The Chicago face database: A free stimulus set of faces and norming data. *Behavior Research Methods, 47*(4), 1122–1135. https://doi.org/10.3758/s13428-014-0532-5
Massar, S. A., Sasmita, K., Lim, J., & Chee, M. W. (2018). Motivation alters implicit temporal attention through sustained and transient mechanisms: A behavioral and pupillometric study. *Psychophysiology, 55*(12), e13275. https://doi.org/10.1111/psyp.13275
Mathôt, S., & Naber, M. (2018). There is no evidence that pupil mimicry is a social phenomenon. *Proceedings of the National Academy of Sciences*, 201814429
Mattavelli, S., Brambilla, M., & Kret, M.E. (in press). It is written in the eyes: Inferences from pupil size and gaze orientation shape interpersonal liking. *Social Cognition*.
Mende-Siedlecki, P., Said, C. P., & Todorov, A. (2013). The social evaluation of faces: A meta-analysis of functional neuroimaging studies. *Social Cognitive and Affective Neuroscience, 8*(3), 285–299.
Olivola, C. Y., Funk, F., & Todorov, A. (2014). Social attributions from faces bias human choices. *Trends in Cognitive Sciences, 18*(11), 566–570. https://doi.org/10.1016/j.tics.2014.09.007
Oosterhof, N. N., & Todorov, A. (2008). The functional basis of face evaluation. *Proceedings of the National Academy of Sciences of the United States of America, 105*(32), 11087–11092. https://doi.org/10.1073/pnas.0805664105
Oosterhof, N. N., & Todorov, A. (2009). Shared perceptual basis of emotional expressions and trustworthiness impressions from faces. *Emotion, 9*(1), 128.
Porter, S., ten Brinke, L., & Gustaw, C. (2010). Dangerous decisions: The impact of first impressions of trustworthiness on the evaluation of legal evidence and defendant culpability. *Psychology, Crime & Law, 16*(6), 477–491. https://doi.org/10.1080/10683160902926141
Prochazkova, E., & Kret, M. E. (2017). Connecting minds and sharing emotions through mimicry: A neurocognitive model of emotional contagion. *Neuroscience & Biobehavioral Reviews, 80*, 99–114.
Prochazkova, E., Prochazkova, L., Giffin, M. R., Scholte, H. S., De Dreu, C. K., & Kret, M. E. (2018a). Reply to Mathot and Naber: Neuroimaging shows that pupil mimicry is a social phenomenon. *Proceedings of the National Academy of Sciences, 115*(50), E11566–E11567.
Prochazkova, E., Prochazkova, L., Giffin, M. R., Scholte, H. S., De Dreu, C. K. W., & Kret, M. E. (2018b). Pupil mimicry promotes trust through the theory-of-mind network. *Proceedings of the National Academy of Sciences of the United States of America, 115*(31), E7265–E7274. https://doi.org/10.1073/pnas.1803916115

Rizzolatti, G., & Sinigaglia, C. (2016). The mirror mechanism: A basic principle of brain function. *Nature Reviews Neuroscience, 17*(12), 757.

Ro, T., Russell, C., & Lavie, N. (2001). Changing faces: A detection advantage in the flicker paradigm. *Psychological Science, 12*(1), 94–99. https://doi.org/10.1111/1467-9280.00317

Robinson, G. K. (1991). That BLUP is a Good Thing: The Estimation of Random Effects. *Statistical Science., 6*(1), 15–32.

Rudebeck, P. H., Putnam, P. T., Daniels, T. E., Yang, T., Mitz, A. R., Rhodes, S. E., & Murray, E. A. (2014). A role for primate subgenual cingulate cortex in sustaining autonomic arousal. *Proceedings of the National Academy of Sciences, 111*(14), 5391–5396. https://doi.org/10.1073/pnas.1317695111

Rule, N. O., Tskhay, K. O., Brambilla, M., Riva, P., Andrzejewski, S. A., & Krendl, A. C. (2015). The relationship between anti-gay prejudice and the categorization of sexual orientation. *Personality and Individual Differences, 77*, 74–80.

Sakuta, Y., Kanazawa, S., & Yamaguchi, M. K. (2018). Infants prefer a trustworthy person: An early sign of social cognition in infants. *PloS one*, *13*(9), e0203541.

Santos, S., Almeida, I., Oliveiros, B., & Castelo-Branco, M. (2016). The role of the amygdala in facial trustworthiness processing: A systematic review and meta-analyses of fMRI studies. *PLoS ONE, 11*(11), 1–28. https://doi.org/10.1371/journal.pone.0167276

Saxe, R., & Wexler, A. (2005). Making sense of another mind: The role of the right temporo-parietal junction. *Neuropsychologia, 43*(10), 1391–1399.

Schaafsma, S. M., Pfaff, D. W., Spunt, R. P., & Adolphs, R. (2015). Deconstructing and reconstructing theory of mind. *Trends in Cognitive Sciences, 19*(2), 65–72.

Schurz, M., Radua, J., Aichhorn, M., Richlan, F., & Perner, J. (2014). Fractionating theory of mind: A meta-analysis of functional brain imaging studies. *Neuroscience & Biobehavioral Reviews, 42*, 9–34.

Seidel, E. M., Habel, U., Kirschner, M., Gur, R. C., & Derntl, B. (2010). The impact of facial emotional expressions on behavioral tendencies in women and men. *Journal of Experimental Psychology: Human Perception and Performance, 36*(2), 500.

Schneider, M., Leuchs, L., Czisch, M., Sämann, P. G., & Spoormaker, V. I. (2018). Disentangling reward anticipation with simultaneous pupillometry/fMRI. *NeuroImage, 178*, 11–22. https://doi.org/10.1016/j.neuroimage.2018.04.078

Senju, A., & Johnson, M. H. (2009). The eye contact effect: Mechanisms and development. *Trends in Cognitive Sciences, 13*(3), 127–134.

Slepian, M. L., Young, S. G., Rule, N. O., Weisbuch, M., & Ambady, N. (2012). Embodied impression formation: Social judgments and motor cues to approach and avoidance. *Social Cognition, 30*(2), 232–240.

SR Research Ltd. (2009). EyeLink® 1000 User Manual, Version 1.5.0, Mississauga, Ontario, Canada

Stewart, L. H., Ajina, S., Getov, S., Bahrami, B., Todorov, A., & Rees, G. (2012). Unconscious evaluation of faces on social dimensions. *Journal of Experimental Psychology: General, 141*(4), 715–727. https://doi.org/10.1037/a0027950

Theeuwes, J., & Van der Stigchel, S. (2006). Faces capture attention: Evidence from inhibition of return. *Visual Cognition, 13*(6), 657–665. https://doi.org/10.1080/13506280500410949

Todorov, A. (2008). Evaluating faces on trustworthiness: An extension of systems for recognition of emotions signaling approach/avoidance behaviors. *Annals of the New York Academy of Sciences, 1124*(1), 208–224. https://doi.org/10.1196/annals.1440.012

Todorov, A., Baron, S. G., & Oosterhof, N. N. (2008). Evaluating face trustworthiness: A model based approach. *Social Cognitive and Affective Neuroscience, 3*(2), 119–127.

Todorov, A., Olivola, C. Y., Dotsch, R., & Mende-Siedlecki, P. (2015). Social attributions from faces: Determinants, consequences, accuracy, and functional significance. *Annual Review of Psychology, 66*, 519–545.

Todorov, A., Pakrashi, M., & Oosterhof, N. N. (2009). Evaluating Faces on Trustworthiness After Minimal Time Exposure. *Social Cognition, 27*(6), 813–833. https://doi.org/10.1521/soco.2009.27.6.813

Tskhay, K. O., & Rule, N. O. (2013). Accuracy in categorizing perceptually ambiguous groups: A review and meta-analysis. *Personality and Social Psychology Review, 17*(1), 72–86. https://doi.org/10.1177/1088868312461308

Van Breen, J. A., De Dreu, C. K., & Kret, M. E. (2018). Pupil to pupil: The effect of a partner's pupil size on (dis) honest behavior. *Journal of Experimental Social Psychology, 74*, 231–245.

Vecchiato, G., Toppi, J., Maglione, A. G., Olejarczyk, E., Astolfi, L., Mattia, D., ... & Babiloni, F. (2014). Neuroelectrical correlates of trustworthiness and dominance judgments related to the observation of political candidates. *Computational and mathematical methods in medicine*, *2014*.

Weibel, D., Stricker, D., Wissmath, B., & Mast, F. W. (2010). How socially relevant visual characteristics of avatars influence impression formation. *Journal of Media Psychology*.

Willis, J., & Todorov, A. (2006). First Impressions: Making Up Your Mind After a 100-Ms Exposure to a Face. *Psychological Science, 17*(7), 592–598. https://doi.org/10.1111/j.1467-9280.2006.01750.x

Wilson, J. P., & Rule, N. O. (2015). Facial trustworthiness predicts extreme criminal-sentencing outcomes. *Psychological Science, 26*(8), 1325–1331. https://doi.org/10.1177/0956797615590992

Wilson, J. P., & Rule, N. O. (2016). Hypothetical sentencing decisions are associated with actual capital punishment outcomes: The role of facial trustworthiness. *Social Psychological and Personality Science, 7*(4), 331–338. https://doi.org/10.1177/1948550615624142

Zebrowitz, L. A. (1997). Reading faces: Window to the soul? Boulder, CO: Westview

Zebrowitz, L. A., & Montepare, J. M. (2008). Social psychological face perception: Why appearance matters. *Social and Personality Psychology Compass, 2*(3), 1497–1517.