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Pupil mimicry and trust – Implication for depression

Katharina S. Wehebrink[a,c,d,1], Katja Koelkebeck[d,1], Simon Piest[e], Carsten K.W. de Dreu[b,c], Mariska E. Kret[a,c,*]

[a] Leiden University, Cognitive Psychology Unit, Wassenaarseweg 52, 2333 AK Leiden, The Netherlands
[b] Leiden University, Department of Social Psychology, Wassenaarseweg 52, 2333 AK Leiden, The Netherlands
[c] Leiden Institute for Brain and Cognition (LIBC), 2300 UC Leiden, The Netherlands
[d] University of Muenster, School of Medicine, Department of Psychiatry and Psychotherapy, Albert-Schweitzer-Campus 1, A9, 48149 Muenster, Germany
[e] Martin-Luther-University Halle-Wittenberg, School of Law and Economics, Große Steinstrasse 73, 06108 Halle (Saale), Germany

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ABSTRACT

Individuals suffering from depression often have difficulty trusting others. Previous research has shown a relationship between trust formation and pupil mimicry - the synchronization of pupil sizes between individuals. The current study therefore examined whether pupil mimicry is weaker in depressed individuals and an underlying factor of their low levels of trust. Forty-two patients with major depressive disorder (MDD) and 40 healthy control subjects played trust games with virtual partners. Images of these partners' eye regions were presented to participants before they had to make a monetary investment decision. Partners' pupils either dilated, constricted, or remained static over the course of 4-s interactions. During the task, participants' pupil sizes were recorded with eye-tracking equipment to assess mimicry. The results confirm that patients with MDD were somewhat less trusting than controls and used another's pupillary cues differently when deciding to trust. Specifically, whereas healthy controls trusted partners with dilating pupils more than partners with constricting pupils, patients with MDD particularly trusted partners whose pupils changed in size less, regardless of whether partners' pupils were dilating or constricting. This difference in investment behavior was unrelated to differences in pupil mimicry, which was equally apparent in both groups and fostered trust to the same extent. Whereas lower levels of trust observed in patients with MDD could not be explained by differences in pupil mimicry, our data show that pupil dilation mimicry might help people to trust. These findings provide further evidence for the important role of pupil size and pupil mimicry in interpersonal trust formation and shed light on the pathophysiology of clinically low trust in patients with MDD.

1. Introduction

The ability to trust others is pivotal to social life, yet patients with depression have difficulties in trusting others (Kupferberg et al., 2016). In contrast to healthy individuals, they do not have the positive expectation that sharing emotions with others fosters help and cooperation (Lewis and Weigert, 1985). In our daily lives, we often have to assess trustworthiness in strangers. In order to evaluate a counterpart's trustworthiness, we rely on various indicators of a safe interaction, such as emotional expressions, bodily gestures, or group membership (Dunn and Schweitzer, 2005; Oosterhof and Todorov, 2008).

Patients with depression have been shown to focus on their internal world and have impaired social skills (Segrin, 2000; Silk et al., 2008), which include deficits in emotion recognition (Kret and Ploeger, 2015), the avoidance of eye contact (e.g., Segrin, 2000), impaired theory of mind abilities (Koelkebeck et al., 2017)and difficulties in building trustful relationships (Lester and Gatto, 1990; Muris et al., 2001). The ability to process signals of trust and translate them into behavior seems impaired, which might also be related to patients' lower levels of cooperation, relatively egocentric behavior, and limited perspective-taking ability (Brendan Clark et al., 2013; Cusi et al., 2013).

Previous studies that showed deficits in emotion processing in depressed patient groups mainly included stimuli with explicit, prototypical facial expressions (Rubinow and Post, 1992; Gilboa-Schechtman et al., 2002; Langenecker et al., 2005; Gollan et al., 2008; Kret and Ploeger, 2015). Conversely, expressions in real life are usually more ambiguous and subtle, yet sufficient to foster trust and social support (Kret, 2015; Aviezer et al., 2012). Direct eye contact provides the most powerful mode of sharing subtle expressions.

For humans, eyes do not only have a visual function, but also serve

* Corresponding author. Wassenaarseweg 52, 2333 AK, Leiden, The Netherlands.
E-mail address: m.e.kret@fsw.leidenuniv.nl (M.E. Kret).
[1] Shared first authorship.

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Table 1
Demographics and test scores of participants.

	Mean (SD)		Mean differences	
	MDD group (N = 42)	Control group (N = 40)	χ^2 / *t* / *F* test values	*p* value
Gender (m/f)	23/19	23/17	χ^2 (1) = 0.062	0.803
Age	39.26 (11.46)	39.73 (10.91)	*t* (80) = 0.187	0.852
HDRS	14.61 (5.83)[a]	0.65 (1.14)	*t* (79) = 14.864	**< 0.001**
Duration of illness (in years)	3.33 (5.19)	–	–	–
EQ	47.40 (40.89)	42.15 (37.98)	*t* (80) = 0.602	0.549
Arousal	2.399,598 (115.46)	1.775,887 (119.81)	*F* (1, 4.309) = 14.051	**< 0.001**
Reaction time	1.42 (0.73)	1.28 (0.75)	*F* (1, 4412) = 1.952	0.162
School years	11.57 (1.52)	11.80 (1.49)	*t*(80) = 0.688	0.493
IQ (MWTB)	107.64 (12.09)	116.83 (16.41)	*t*(80) = 2.894	**0.005**

HDRS: Hamilton Depression Rating Scale (21 items, (32)): measures depressive symptoms.
EQ: Empathy Quotient (60 items, (34)): measures empathic abilities in adults.
Arousal: Participants' stimulus-unrelated pupil size, i.e., participants' average pupil size 200–400ms prior to stimulus onset. The stimulus-unrelated pupil size might indicate participants' general level of arousal unrelated to the stimulus material.
IQ MWTB: Multiple Choice Vocabulary Test (35): measures premorbid intelligence.
Note: Significant differences are marked bold.
[a] Score of one participant is missing.

as a reference point to be seen by others (Tomasello et al., 2007). The pupil dilates or constricts not only in response to different lighting conditions, but also in response to emotion and thought (Goldwater, 1972; Loewenfeld, 1993; Laeng et al., 2012). By observing the pupil, significant information about the emotional, mental or cognitive state of another person can be acquired (Kahneman and Beatty, 1966). Because pupillary responses are autonomic and uncontrollable (Loewenfeld, 1993), they can provide important and reliable social information to observers. Several studies using pupillometry demonstrated pupil dilation upon viewing pictures with arousing or emotionally relevant stimuli (Peavler and McLaughlin, 1967; Kret et al., 2013a, 2013b). Furthermore, larger pupil sizes are associated with increased approach behavior and attractiveness in humans (Laeng and Falkenberg, 2007; Wiseman and Watt, 2010) and yield honest, non-deceptive behaviours (van Breen et al., 2018).

Recently, it has been shown that people implicitly mimic the pupil size of their interaction partners (Kret et al., 2015) and that paying attention to other peoples' pupils and mimicking their changes in size helps to determine the trustworthiness of a partner (Kret et al., 2015; Kret and de Dreu, 2017). In these two studies, healthy individuals trusted partners with dilating pupils more than partners with static pupils and, especially so, when their pupils synchronized, i.e., when participants' pupils dilated along with the dilating pupils of the partner (Kret and de Dreu, 2017; Kret et al., 2015). Thus, participants based assessments of trustworthiness on their partners' pupil size. This stresses the relevance of pupil mimicry in the establishment of trust and suggests that a lack of pupil mimicry could account for lower levels of trust (Kret et al., 2015). From that point of view, we may hypothesize that lower levels of trust in depressed individuals (Lester and Gatto, 1990) stem from a failure to mimic the pupil sizes of interaction partners. That is, patients might fail to implicitly infer trust from own and others' pupil sizes.

In sum, a major characteristic of depression is its impairment in social functioning, including a lack of trust in others (Lee et al., 2005; Muris et al., 2001). Although these difficulties in depressed individuals are pervasive, a detailed understanding of the cognitive mechanisms underlying these deficits has not been reached. Because recent research findings point to an important role of pupil mimicry in social interaction and trust decisions in particular (Kret et al., 2015), the pupil is introduced to contribute to a better understanding of depression.

The current study examined the relationship between pupil mimicry and trust in patients with a clinically diagnosed episode of a major depressive disorder (MDD) as compared to a healthy control group. First, it was examined whether the participants' pupil sizes synchronize with a partner's dilating or constricting pupils as compared to partner's static pupils. Second, it was tested whether there is a difference in pupil mimicry between depressed individuals and healthy controls and third, whether pupil mimicry influences trust decisions in the two groups.

2. Methods and materials

2.1. Participants and clinical assessment

A total of 106 participants were recruited from the University Hospital Muenster, Department of Psychiatry and Psychotherapy, Germany. The sample included 64 patients with a single or recurrent episode of MDD and 42 healthy controls.

In total, nineteen patients had to be excluded. Six patients were excluded due to a concurrent anxiety disorder, two due to concurrent severe personality disorder, three due to technical issues, three due to not meeting criteria for a depressive episode any longer and five patients due to not meeting a major depressive episode as regarding the DSM-criteria. In addition, two control participants were excluded because they had a lifetime diagnosis of MDD or panic disorder. Three other participants were excluded because they could not complete the task due to technical difficulties. Therefore, the statistical analyses are based on a sample size of 42 patients with MDD (*mean age* = 39.26, *SD* = 11.45) and 40 healthy controls (*mean age* = 39.56, *SD* = 11.00). There were no significant differences between the two groups in terms of age ($t(80) = 0.187$, $p = 0.852$), gender (χ^2 (1) = 0.062, $p = 0.803$), or years of education ($t(80) = 0.688$, $p = 0.493$; see Table 1 for an overview of all demographic variables). While patients volunteered, controls received a compensation of €20, following standard guidelines of the local ethics committee. All participants took part in the Structured Clinical Interview for DSM-IV (First et al., 1996) to confirm patients' diagnoses of MDD and to rule out any other mental disorders in patients and control subjects. For patients, all Axis-I disorder other than depression or severe Axis-II mental disorders qualified as exclusionary criteria. Furthermore, the Hamilton Depression Rating Scale (Hamilton, 1967) was conducted to rate depressive symptoms and their severity in both groups. Thirty-five of the patients in the final sample received antidepressant or mood-stabilizing medication (SNRI: 7; SSRI: 6; NaSSA: 5; NDRI: 4; tricyclic antidepressant: 2; MAO-inhibitor: 1; mood stabilizer: 1; atypical antipsychotic: 1; two-fold combination of SNRI and NaSSA: 4; NDRI and melatonin-derivative: 1; SSRI and melatonin-derivative: 1; three-fold medication of SNRI, NaSSA and melatonin-

derivative: 1; SSRI, SNRI and melatonin-derivative: 1; combination with atypical antipsychotic: 19; combination with mood stabilizer: 3; Z-drug: 1). For control subjects, any history of mental disorder constituted an exclusion criterion. All subjects had (corrected to) normal visual acuity, as assessed with the Snellen eye chart (Snellen, 1862).

The study was approved by the local ethics committee (2012-495-f-S) and the internal review board of the University of Amsterdam (2012-WOP-2159). It also conformed to the Declaration of Helsinki (http://www.wma.net/en/30publications/10policies/b3/index.html; access: 17 November 2017). All participants were informed in detail about the protocol of the study and provided written informed consent.

2.2. Procedure

All participants were tested individually. Prior to the task, subjects completed two self-report questionnaires (see Table 1). Subjects were then familiarized with the eye-tracking procedure (including checking for sufficient visual acuity and the dominant eye) and the trust game task (Berg et al., 1995). Following, they were seated in front of a computer screen (1.280x1.024px) with a distance of ~50 cm. To minimize movement, the head was placed on a head stabilizer. The room was darkened so that the only light sources were the stimulus screen and the experimenter's computer screen (which was not visible to the participant). After a successful nine-point calibration of the eye-tracker (EyeLink, SR Research, Ottawa, Canada), participants started the trust game. The first three trials were practice trials. After the first half (27 trials) there was a break of 1 min for subjects to rest their eyes.

After the experiment, participants were debriefed about the goal of the study and their gain for a randomly picked trial was paid in candy.

2.3. Task

2.3.1. Trust game

Participants were instructed to play incentivized trust games with different virtual partners of whom only a video clip of the eye region was shown. In a series of 54 trials, they decided to invest 0, 2, 4 or €6 in their partner. Each trial started with a scrambled version of the stimulus. After 3.000 ms, a grey fixation cross appeared in the middle of the scrambled image. To verify that the subjects' eyes were directed towards the relevant part of the screen, the stimulus only appeared after their gaze fell within an area of interest around the fixation cross (70x70px) for 1.000 ms. The pupils in all stimuli stayed static for 1.500 ms. Then, the pupils dilated, constricted, or remained static for another 1.500 ms (see Supplemental Information S1). In all three conditions, partners' pupils were static during the final 1.000 ms of stimulus presentation. After subjects observed the partner for 4.000 ms, they used two response boxes (with two buttons each) to decide how much money they wanted to transfer to their partner (0, 2, 4, or €6, see Supplement S1).

Subjects were told that the transferred amount would be tripled and credited to their partner, who could then decide how much he/she wanted to retransfer to the participant. No feedback was given in between trials. After a button press, the next trial started with its respective scramble.

The experiment used a fully randomized design. In addition to the investment decisions, we measured changes in participants' pupils while they watched the recording of their exchange partner. The trust game was programmed in Presentation (v16.2, Neurobehavioral Systems).

2.4. Stimuli

To create stimulus material for the virtual trust game, photographs of nine men and nine women were standardized using Adobe Photoshop®. This included resizing the images into life size, turning them into grayscale, cropping them to reveal only the eye region, retouching distracting blemishes, and standardizing contrast levels and mean luminosity. The eyes (pupil, iris and parts of the sclera) were removed from the images and replaced by a video layer using Adobe After Effects™ that featured artificial eyes with dilating, constricting or static pupils. Pupil diameter started at 5 mm and either dilated to 7 mm diameter or constricted to 3 mm diameter. In total, this yielded 54 unique stimuli – 18 faces for each of the three conditions of partners' pupils (dilation, constriction, and static). These stimuli constituted the virtual partners in the trust game task. Scrambled versions of the stimuli were created by applying a Fourier transformation with a Gaussian filter to each image using MATLAB Fast Fourier Transform Function (Walker, 1996). This yielded 18 unique pre-stimulus images with the same luminosity and level of detail as the respective stimulus, while lacking any semantic content.

2.5. Data preparation

Participants' pupil sizes and gaze were continuously recorded with 500 Hz using an EyeLink 1000 eye-tracking system (SR Research). Gaps smaller than 250 ms were interpolated. Data was smoothed by applying a 10th order low-pass Butterworth filter. Trials were excluded if more than 50% of the data within that trial were missing (i.e., because the eye-tracker lost the pupil). Outliers were removed with an algorithm using the differences between a subject's subsequent pupil size samples: if this difference was larger than the mean difference plus 1.5 times the standard deviation of the differences, that sample was deleted. In order to improve efficiency of upcoming computations, the data was reduced to 50 Hz by averaging 50 subsequent samples to form one value of pupil size. Visual inspection of line plots confirmed that the reduced amount of data was indeed sufficient to accurately represent the growth curve of pupil size.

The average pupil size of 500 ms of each participant and the trial (thus five values) before the partners' pupils started to change (1.000 ms-1.500 ms after stimulus onset) served as a baseline and was subtracted from all remaining pupil size values (1.600 ms-4.000 ms).

2.6. Statistical analysis

Because of the nested structure of the data, multilevel modeling was the most appropriate method to analyze the data (Hox, 2002; Bagiella et al., 2000). In order to acquire the model with the best fit to the data, we started with a full model and deleted non-significant higher-level terms step by step. Every extinction was checked with the Akaike information criterion (Doherty et al., 2012).

2.6.1. Trust investment decisions

Trusting behavior was analyzed with a series of two-level models defined by the different trials that were nested within participants. Trust decisions served as the dependent variable in all models. Group, partner's pupil, and their interaction served as predictors.

2.6.2. Pupil mimicry

For the participants' pupil analysis, a three-level regression model, defined by pupil size samples (repeated measures) nested within trials and trials nested within subjects, was used Linear Mixed Model, implemented in SPSS Version 22.0, (Bagiella et al., 2000,West et al., 2006). Time was added as a repeated factor with a First-Order Autoregressive covariance structure (AR1) in order to control for auto-correlation over time points. The baseline corrected pupil size served as the dependent variable. The factors Partner's Pupil (constriction vs. static vs. dilation, coded as −1, 0 and 1 respectively) and Group (MDD vs. controls, coded as −1 and 1) and their interactions served as predictors. Furthermore, three orthogonal polynomials were included to account for linear, quadratic, and cubic trends in the growth curves. A

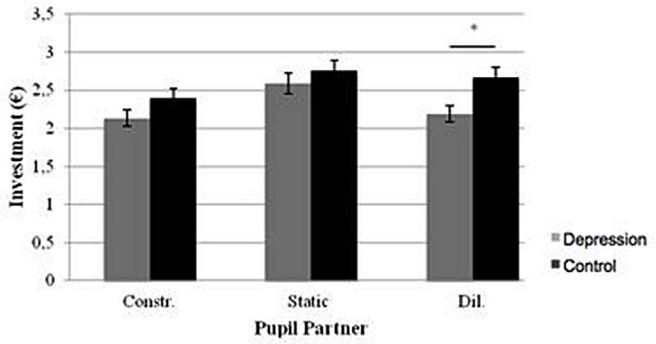

Fig. 1. Mean trust levels of MDD patients and controls in the constriction, dilation and static condition. Error bars indicate ± 1 SE. (*$p < 0.05$).

random intercept and random linear, quadratic and cubic terms accounted for individual differences. Furthermore, a random effect of Actor was examined.

To further investigate the source of trust, participants' pupil responses were separated based on a median split into Dilation Mimicry trials or Constriction Mimicry trials. For example, a trial was categorized as a "dilation mimicry trial" or a "constriction mimicry trial" when the mean pupil size of the trial was higher than the median pupil size of a participant when viewing a partner with dilating pupils or when viewing a partner with constricting pupils. The statistical models included the factors Group, Type of Mimicry (Dilation Mimicry or Constriction Mimicry) and the interaction between the two.

To further investigate whether possible differences between patients with MDD and controls were related to depressed mood or to other unforeseen mediating factors, including level of arousal ($F(1,4309) = 14.051$, $p < 0.001$), those factors were explored and added as additional predictors to the analyses.

3. Results

3.1. Trust investment decisions

There was a trend towards a main effect of group, showing that patients had slightly lower levels of trust than controls ($F(1, 4.408) = 3.356$, $p < 0.061$). A significant Group x Partner's Pupil interaction ($F(2, 4.408) = 4.188$, $p = 0.015$), however, indicated that patients trusted partners with pupils that changed in size less than control participants ($F(2, 4.408) = 28.00$, $p < 0.001$). Replicating our earlier findings (Kret and de Dreu, 2017; Kret et al., 2015), control participants trusted partners with constricting pupils less than partners with static or dilating pupils (constricting versus static: $t(4.408) = 4.564$, $p < 0.001$; constricting versus dilating: $t(4.408) = 3.417$, $p < 0.001$; dilating versus static: $t(4.408) = 0.090$, $p = 0.250$). In contrast, patients with MDD trusted partners with dilating or constricting pupils *less* than partners with static pupils (dilating versus static pupils: $t(4.408) = 5.239$, $p < 0.001$; constricting versus static pupils: $t(4.408) = 5.968$, $p < 0.001$; dilating versus constricting pupils: $t(4.408) = 0.729$, $p = 0.466$, see Fig. 1).

3.2. Pupil mimicry

Results show that participants' pupil sizes in both groups mimicked partners' pupil size, as indicated by a significant main effect of Partner's Pupil ($F(2, 105.805) = 6.087$, $p = 0.002$). In addition, a Partner's Pupil x Linear trend interaction was observed ($F(2, 105.805) = 10.944$, $p < 0.001$). As predicted, participants' pupils increased fastest when partners' pupils dilated (see Table S2c in Supplement S2 for all statistical models).

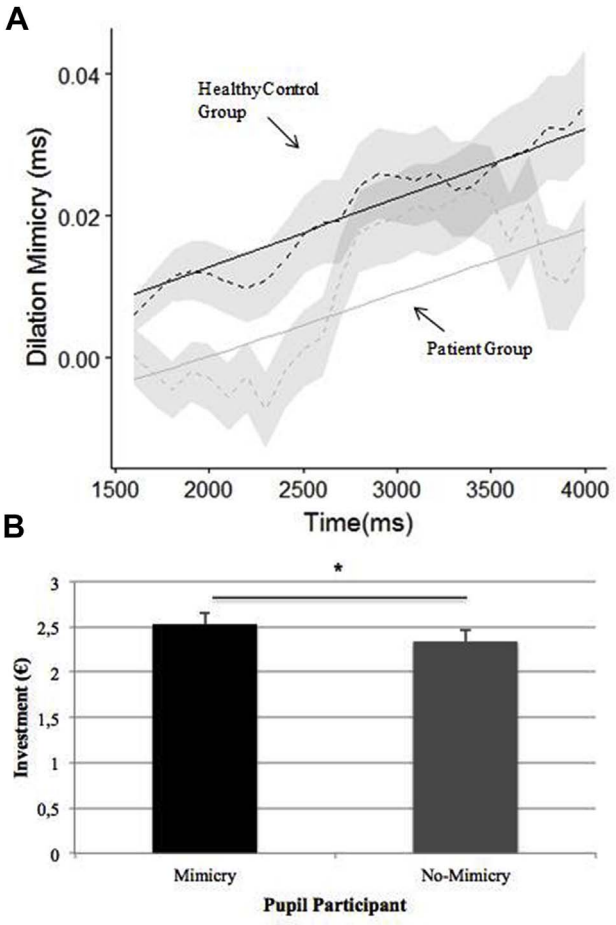

Fig. 2. *(A)* Mean dilation mimicry in response to partners' pupils are shown as a function of time. Here, dilation mimicry was measured by subtracting participants' pupil diameters when partners' pupils were static from the mean amount that participants' pupils expanded in response to similar changes in the partners' pupils. The shaded bands indicate 1 SE, the solid lines show predicted data, and the dashed lines show observed data. (*B*) Mean investments for dilation mimicry trials for all participants (*$p < 0.05$).

3.3. Dilation mimicry's and constriction mimicry's effect on trust

In our previous studies we observed a positive relationship between pupil dilation mimicry and trust, and in one of the two studies we observed an additional relationship between pupil constriction mimicry and lower trust (Kret et al., 2014, 2015; Kret and de Dreu, 2017). In the current study, results showed a significant effect of pupil dilation mimicry ($F(1, 1.432) = 3.873$, $p = 0.049$), indicating that participants invested more in partners with dilating pupils if their own pupils mimicked their partner's pupils (see Fig. 2). Nevertheless, no significant interaction effect between group and pupil dilation mimicry was found ($F(1,1.432) = 3.523$, $p = 0.061$). The absence of an interaction indicates that depressed patients benefitted as much from pupil mimicry as controls.

No significant effects of constriction mimicry were observed ($p \geq 0.118$; see Table S2c in Supplement S2 for all statistical models).

3.4. Potential confounding variables

We checked whether differences between patients and controls on questionnaire scores, general level of state arousal and IQ scores impacted on the above presented results. As none of these factors could explain the differences between the groups in terms of investment behavior or the lack of differences in terms of pupil mimicry and its link to trust, the respective analyses are presented in the Supplement.

4. Discussion

In this first investigation of trust game decisions in patients with MDD, we examined whether decisions in patients compared to controls were differentially influenced by partners' pupillary changes and subjects' propensity to mimic these changes. We here showed an atypical investment pattern in patients but normal pupil mimicry behavior. Furthermore, pupil dilation mimicry in healthy controls and patients alike was positively associated with higher levels of trust, corroborating the previously established effect of pupil dilation mimicry on trust (Kret et al., 2015; Kret and de Dreu, 2017).

Patients with MDD tend to have difficulties with building trustful bonds (Lester and Gatto, 1990; Muris et al., 2001; Kim et al., 2012; Hammen and Brennan, 2001; Lewinsohn et al., 1998). They show lower levels of cooperation, egocentric behavior, and have a limited ability of perspective taking (Brendan Clark et al., 2013; Cusi et al., 2013). Their reduced ability in processing social signals hampers the recognition of friendly and safe interaction partners whose prosocial signals fail to get translated into trusting behavior. This impairment might also explain patients' maladaptive social interaction behaviors. The current study confirmed that patients with MDD show atypical levels of trust compared to healthy control participants. Most intriguingly, when partners' pupils changed in size, trust investments by patients stayed ~15% behind those of control participants.

In previous research, we observed that the pupil sizes of interaction partners tend to synchronize and that this adaptation promotes trust (Kret et al., 2015; Kret and de Dreu, 2017). Mimicry of another persons' behavior, be it pupillary changes (Kret et al., 2015; Destoop et al., 2012), facial expressions (Hatfield et al., 1993; Hess and Blairy, 2001) or gestures (Chartrand and Bargh, 1999), grounds positive feelings and has a positive impact on the bond between individuals (van Baaren et al., 2004; Simms, 1967; Hess and Fischer, 2013; Harrison et al., 2006; Kret et al., 2015). However, research in patients with MDD has shown that they display less facial mimicry than healthy controls (Wexler et al., 1994; Likowski et al., 2011). In contrast to our prediction, the current study shows that both groups mimicked the pupil sizes of their partners equally, and pupil dilation mimicry predicted higher levels of trust in both groups. This finding might indicate that this basic and automatic mechanism works equally well in both groups.

A clear difference, however, revealed itself in the trust decisions between the patient group and the control group. Previous research has shown that generally, people with large or dilating pupils are perceived more positively and are trusted more than people with small or constricting pupils (Hess, 1975; Demos et al., 2008; Kret et al., 2015; Kret, 2017). Yet, our findings indicate that patients with MDD trusted less than healthy controls, especially when partners' pupils changed in size. Changes in pupil size within a social setting can reflect changes in attention, arousal and interest (Granholm and Steinhauer, 2004) and are all potentially salient social cues. One possible interpretation of our results is that patients avoided partners showing these cognitive or emotional changes and preferred a more stable partner. Depressed patients might try to avoid social interactions in order to prevent the rejection and/or punishment of another person (Destoop et al., 2012). Their unusual trust reaction pattern might therefore reflect their general avoidance of social signals as proposed in previous research by Radke et al. (2014) who found that depressed patients did not adjust their behavior to varying interpersonal cues. In addition, it has also been shown that patients with MDD are less adept at recognizing emotional expressions (Bourke et al., 2010; Demenescu et al., 2010; Dalili et al., 2015). As pupil dilation is an expression of arousal (Bradley et al., 2008; van Steenbergen et al., 2011), which can be seen as an emotional cue or expression, patients with MDD might be impaired in their ability to correctly recognize these emotional expressions, and therefore do not show increased trusting behavior as in healthy individuals. In both explanatory models, a differentiation between partners with dilating or constricting pupils might be either undesirable or impossible, and the result might be a distrustful stance towards these game partners.

Instead of a possible difference in social search strategies or emotion recognition deficit between patients and controls, a more biological explanation involves dysfunctional stimulus processing due to altered activation patterns in brain networks that are important for emotion recognition, perspective-taking, and social judgment (Kret and Ploeger, 2015). Neuroimaging research on how depression influences social decision-making has been scarce, but the limited evidence suggests that there might be a link between disrupted neural networks and trust deficits (Drevets et al., 2008; Johnstone et al., 2007). Gradin et al. (2016) showed that depressed patients reacted less positively in response to pro-social offers in an ultimatum game, which was reflected in dampened activation of reward networks in the brain. In a prisoner's dilemma game, depressed participants also showed decreased dorsolateral prefrontal cortex activation during unreciprocated cooperation (Gradin et al., 2016). These abnormalities might be one possible factor that leads to abnormal trust behavior.

Furthermore, hormonal and genetic factors could play an additional role. For example, imbalanced levels of brain serotonin (5-HT) (Sachs et al., 2015; Jacobsen et al., 2012) and mutations within the 5-HT gene seem to be associated with depression (Karg et al., 2011; Caspi et al., 2003). Pharmacological studies suggest that the 5HT neurotransmitter plays a crucial role in social cognition including prosociality (Cerit et al., 2015), cooperative behavior (Crockett, 2009), interpersonal trust (Colzato et al., 2013), and economic decision-making (Crişan et al., 2009). Thus, depressed individuals differ from healthy controls in the neurochemical substrates involved with processing social information. However, future research should aim to disentangle the different potential factors contributing to trust deficits in depression.

Another important finding of this study is that pupil dilation mimicry helps participants to trust more. This positive effect of mimicry could be beneficial for those people with low trust. Yet, investigating patients with different levels of depression severity is necessary to examine whether patients with MDD would specifically benefit from mimicking pupil sizes and to corroborate our results. It is possible that severely affected patients with MDD might benefit more from mimicry than patients with lesser symptoms. This possibility arises from previous research indicating that cognitive and neural processing biases are affected by the severity of the depression (e.g., Dannlowski et al., 2007; Suslow et al., 2010) and that more severely depressed patients might benefit from an assessment of pupillary responses as a prognostic indicator (Siegle et al., 2011). Thus, this might have important therapeutic implications: ideally, by stimulating patients to make more eye contact with others, interpersonal trust can be increased and social relationships (re)established. The eye region is crucial for social behavior. From the first days of life, infants are specifically attuned to this region (Farroni et al., 2002). Not only does it provide important social and emotional cues, but also a number of previous studies showed that focusing on the eyes helps patients with amygdala damage or autism to recognize emotions (Spezio et al., 2006; Adolphs et al., 2005). Increasing eye contact might stimulate the processing of an interaction partner's pupillary changes, boost pupil mimicry, and subsequently help them to trust more. Nonetheless, future studies are needed to support this claim.

A limitation of the current study is that most depressed participants used antidepressant medication that can affect norepinephrine levels, and thereby influence pupil size (Gould et al., 2006; Nieuwenhuis and Jepma, 2011; Gabay et al., 2011). We tested whether medication normalized the deviant investment pattern observed in patients; although that does seem to be the case, we cannot rule out alternative explanations (see Supplement S3 for a detailed overview). Thus, in future studies it would be important to include a larger group of non-medicated depressed patients and further investigate effects of medication (Sheline et al., 2001). Another limitation worth mentioning is that patients volunteered in the study whereas control subjects were paid,

which could have led to differences in investment behaviours between the groups.

4.1. Conclusion

The current study explored the link between pupil mimicry and trust in patients with MDD. Results confirmed patients' lower levels of trust and altered investment patterns based on a partners' pupillary signals. Yet, patients with MDD showed intact pupil mimicry, and a relationship between pupil dilation mimicry and trust was identified. These findings underline the important role of pupil size and pupil mimicry in interpersonal trust and social interaction, which might have significant clinical implications for patients with social deficits.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jpsychires.2017.11.007.

Conflicts of interest

None.

Author declaration

All authors have seen and approved the final article. They warrant that the article is the authors' original work, hasn't received prior publication and is not under consideration for publication elsewhere.

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