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Social Effects of Tears and Small Pupils Are Mediated by Felt Sadness: An Evolutionary View

Dennis Küster[1,2]

Abstract

Small pupils elicit empathic socioemotional responses comparable to those found for emotional tears. This might be understood in an evolutionary context. Intense emotional tearing increases tear film volume and disturbs tear layer uniformity, resulting in blurry vision. A constriction of the pupils may help to mitigate this handicap, which in turn may have resulted in a perceptual association of both signals. However, direct empirical evidence for a role of pupil size in tearful emotional crying is still lacking. The present study examined socioemotional responses to different pupil sizes, combined with the presence (absence) of digitally added tears superimposed upon expressively neutral faces. Data from 50 subjects showed significant effects of observing digitally added tears in avatars, replicating previous findings for increased perceived sadness elicited by tearful photographs. No significant interactions were found between tears and pupil size. However, small pupils likewise elicited a significantly greater wish to help in observers. Further analysis showed a significant serial mediation of the effects of tears on perceived wish to help via perceived and then felt sadness. For pupil size, only felt sadness emerged as a significant mediator of the wish to help. These findings support the notion that pupil constriction in the context of intense sadness may function to counteract blurry vision. Pupil size, like emotional tears, appears to have acquired value as a social signal in this context.

Keywords

emotional tears, pupil size, signaling, handicap, visual acuity, sadness processing, prosocial behavior, pupil mimicry

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Recent literature suggests that emotional tears (Hasson, 2009; Vingerhoets, 2013; Vingerhoets & Blysma, 2016) or pupil size regulation (Kret, Fischer, & De Dreu, 2015; Prochazkova & Kret, 2017) may serve social signaling functions during a close social interaction. Pupil size regulation is increasingly studied in the context of emotional mimicry. Humans are known to mimic the pupils of their conspecifics (Kret, Tomonaga, & Matsuzawa, 2014), to synchronize pupil diameters in response to others' internal states (Prochazkova & Kret, 2017), and possibly to alter investment decisions depending on a partner's pupillary signals (Wehebrink, Koelkebeck, Piest, Dreu, & Kret, 2018). There is even evidence for a matching of arousal already in infancy (Fawcett, Wesevich, & Gredebäck, 2016). Conversely, there is now little question that emotional tears are significant social signals (Vingerhoets, 2013; Vingerhoets & Blysma, 2016).

Nevertheless, tears and pupil size regulation have rarely been studied together. While the respective physiological functions of tears and pupils are well understood (Oyster, 1999; Trimble, 2012), little is known about how their purported social signaling functions may be interrelated. Initially, a few studies have investigated pupillary responses in sadness processing (Harrison, Singer, Rotshtein, Dolan, & Critchley, 2006; Harrison, Wilson, & Critchley, 2007). In this work, small pupils modulated not only perceived sadness but also appeared closely tied to emotional responses elicited in observers (Harrison et al., 2007). However, Harrison and colleagues examined facial expressions rather than tears. Finally,

[1] Department of Computer Science, University of Bremen, Bremen, Germany
[2] Department of Psychology and Methods, Jacobs University Bremen, Bremen, Germany

Corresponding Author:
Dennis Küster, Department of Computer Science, University of Bremen, Enrique-Schmidt-Str. 5, Bremen 28359, Germany.
Email: kuester@uni-bremen.de

while similar social signaling functions are frequently attributed to both tears and pupil-mimicry, the respective literatures have remained largely separate.

Emotional Tears

The modern scientific study of emotional tears is still young (Vingerhoets, 2013; Vingerhoets & Blysma, 2016). Darwin (1872) has often been cited as having failed to grasp the importance of emotional tears that, to him, appeared "superfluous" (e.g., Vingerhoets, 2013; Vingerhoets & Blysma, 2016). Nevertheless, mounting evidence now suggests that emotional tears serve important social functions, for example, to facilitate perception of sadness and elicit social support (Balsters, Krahmer, Swerts, & Vingerhoets, 2013; de Ven, Meijs, & Vingerhoets, 2017; Hendriks, Croon, & Vingerhoets, 2008; Provine, Krosnowski, & Brocato, 2009; Rottenberg, Blysma, & Vingerhoets, 2008; Vingerhoets, 2013; Vingerhoets & Blysma, 2016; Vingerhoets, de Ven, & van der Velden, 2016).

As Hasson (2009) has suggested, the interference of excessive tears with clear vision may qualify them as a handicap for both aggressive and defensive actions, supporting the notion that they may have evolved as appeasement signals or signals of need. Emotional tears may, thus, be an example of a characteristic trade-off between costs and benefits (cf. Hasson, 1997). However, given the pervasive selection for high visual acuity and importance of optimization in the evolution of the eyes (Goldsmith, 1990; Kay & Kirk, 2000), fallout from such a self-imposed handicap should likely be reduced by other mechanisms, including regulation of pupil size.

Physiological Regulation of Pupil Size and the Impact of Tears

The pupils are well known for their role in helping the eyes adapt to changes in light intensity (Campbell & Gregory, 1960). As first suggested by Denton (1956), a key function of the pupils is to provide optimal apertures for visual acuity at different light intensities. Pupil size linearly increases with light intensity (Cheng, Rao, Cheng, & Lam, 2006). If the pupils are too large under well-lit conditions, image contrast is lost due to optical aberrations, diffraction, and stray light (Campbell & Gregory, 1960). Tears diffuse light and blur vision (Hasson, 2009), suggesting that a reduction in pupil size could be an effective adaptation to help counteract blurry vision.

Research on the *dry eye syndrome* (DES), a medical condition characterized by a lack of tears as well as redness and irritation (e.g., Moshirfar et al., 2014; Nilforoushan, Latkany, & Speaker, 2005) likewise suggests benefits of reduced pupil size in response to tearing. Dynamic changes in tear-layer uniformity (i.e., "blurriness") show the greatest degrading effects at larger pupil diameters (Montés-Micó, 2007). Furthermore, visual quality diminishes for several minutes following the temporary increase in tear volume caused by eye drops administered to treat DES (Tung et al., 2012), illustrating of how excess tears can interfere with vision.

Pupil-Mimicry

Apart from their primary physiological functions, pupil size regulation might serve social signaling functions or it might simply act as an additional cue in sadness perception (see Hasson, 2009). Harrison, Singer, Rotshtein, Dolan, and Critchley (2006) could show that smaller pupil size increased perceived intensity of sad faces, whereas no such effects were observed for neutral, happy, or angry expressions. This finding was replicated in a second study by the same group (Harrison et al., 2007), who extended their previous findings by the provocative observation that participants responded with significantly smaller pupils of their own when viewing sad faces (see also Trimble, 2012). This type of pupil-synchronization, or pupil-mimicry, has been explained as a process of *emotional contagion* (Adolphs, 2006; Harrison et al., 2006; see also Harrison, Gray, & Critchley, 2009), that is, the extent to which observers react with the same type of emotional response as another person they have been observing (Hatfield, Cacioppo, & Rapson, 1993; Hess & Fischer, 2013).

Pupil-mimicry has, indeed, been observed in a substantial number of studies and contexts other than sadness (Kret & De Dreu, 2017; Prochazkova & Kret, 2017). It has been shown to increase trust toward ingroup members (Kret et al., 2015) and appears to be deeply rooted in human evolution to promote within-species communication of inner states, shared understanding (Kret et al., 2014), and sharing of emotions (Prochazkova & Kret, 2017). Whereas sadness and tears have been related to appeasement functions (Hasson, 2009), displays of anger and threatening cues from faces and bodies have been found to elicit pupil dilation (Kret, Roelofs, Stekelenburg, & de Gelder, 2013). In general, these findings appear to align with the notion that reduced pupil size would be consistent with signaling functions attributed to tears.

Aside from appeasement (Hasson, 2009), empirical work on emotional tears has considered to what extent they may function as part of attachment behavior (cf. Bell & Ainsworth, 1972) designed to elicit empathy and help from onlookers (Hasson, 2009; Hendriks et al., 2008; Hendriks, Nelson, Cornelius, & Vingerhoets, 2008; Hendriks & Vingerhoets, 2006; Nelson, 2005; see also Vingerhoets, Bylsma, & Rottenberg, 2009). Further studies (e.g., Cornelius, Nussbaum, Warner, & Moeller, 2000; Provine et al., 2009; Vanman, Sharman, Müller, Horiguchi, & Martin, 2013) have examined tears by contrasting photographs of crying faces with altered versions of the same images from which the tears were digitally removed. In these studies, the removal of tears has consistently been shown to result in a decrease of perceived sadness. Finally, recent research (de Ven, Meijs, & Vingerhoets, 2017) suggests that tearful individuals may be seen as warmer but also as less competent.

Summary

Social signaling functions are increasingly attributed to both tears and emotional pupil size regulation (e.g., Kret & De Dreu,

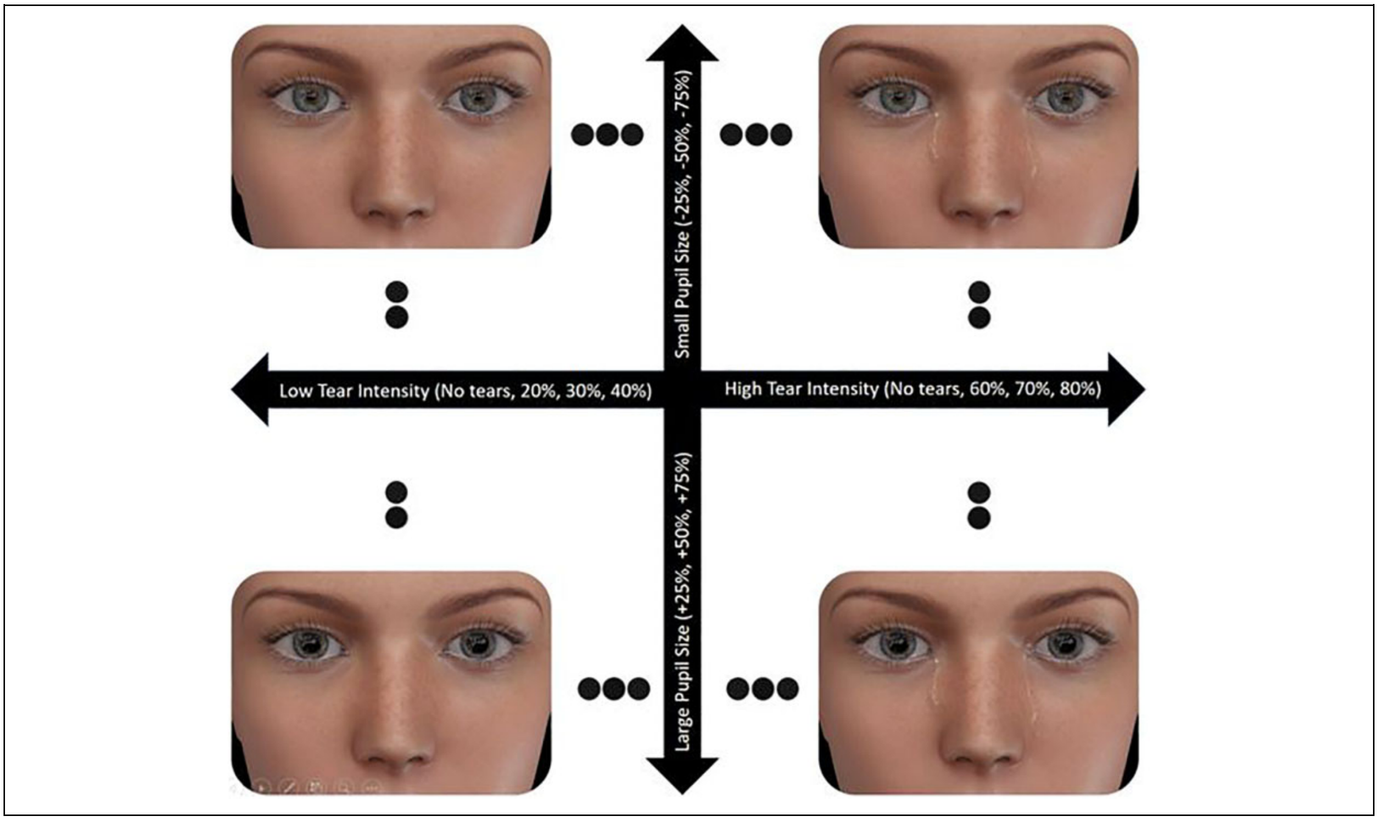

Figure 1. Experimental design and sample stimuli: tearless face with small pupils (upper left), maximally tearful face with small pupils (upper right), tearless face with large pupils (lower left), and maximally tearful face with large pupils (lower right). Images show the respective endpoints of the variation in pupil-size and tear presence of 1 of the 12 characters. Black circles represent the additional within-subjects variation of pupil size (three steps per condition, including the depicted endpoints) and tear intensity (four steps, including no-tear) within each of the four between-subjects conditions. Analyses of between-subjects effects collapsed across the circles represented in each condition. Within-subjects analyses of tear presence compared responses to the tearless stimuli present within each condition to the stimuli containing tears.

2017; Vingerhoets & Blysma, 2016). Biological signaling theory (e.g., Hasson, 1997, 2009) may, therefore, help to predict and explain their interplay and social effects. For the case of emotional tears, Hasson (2009) has already presented several intriguing arguments, emphasizing the role of trade-offs for biological signals, wherein tears might function as a handicap by blurring vision. For the case of emotional pupil size regulation, it is speculated that tears may trigger immediate, or even anticipatory, action of the pupillary system resulting in smaller pupils. In consequence, reduced pupil size might help to elicit social support via some of the same mechanisms as emotional tears. The present work aimed to embark from this framework to examine the social effects, signaling functions, and potential mediating mechanisms of responses to tears and changes in pupil diameter. Toward this aim, participants were exposed to systematic variations of pupil size and the presence (absence) or tears in a perception study.

Participants

Fifty-one participants took part in this 30-min laboratory experiment and were compensated with €3. All participants provided written consent and were fully debriefed. Data from one participant were excluded due to a problem with the recording software. Data from the remaining 50 participants (28 female, $M_{\text{age}} = 20.8$ years, $SD = 2.05$) were submitted to all analyses.

Stimulus Material

Images of 12 Caucasian female characters were created in Poser Pro 2012 (Smith Micro, CA, USA) using photorealistic textures. All stimuli were generated as close-up shots of the upper part of the face extending from slightly above the eyebrows to slightly above the mouth so that neither scalp hair was expected to be seen nor any part of the mouth. The eyebrows and facial expressions of all 12 characters were left in their default neutral position. All images were presented at a resolution of 1280×900 pixels to allow good visibility even of subtle variations in pupil size and tear intensity (Figure 1). Variation in appearance between the Caucasian models was achieved through differences in skin—and eye textures, as well as the differences in facial morphology belonging to the models.

Design and Procedure

Participants were randomly assigned to one of the four between-subjects conditions (2 Pupil Size $\times$ 2 Tear Intensity) of a mixed design presented in E-Prime 2.0 (www.pstnet.com). Within each between-subjects condition, nested randomization was used to show all 12 nonrepeating characters with slightly varying pupil sizes and tear intensity. Pupil diameter was manipulated in poser by setting the size of the morph-controlled pupils to $-.75$, $-.50$, and $-.25$ for the small pupil size conditions, and $+.25$, $+.50$, and $+.75$ for the large pupil size conditions. This manipulation resulted in a 300% increase in pupil diameter between the smallest pupils in the small pupil size condition, and the largest pupils in the large pupil size condition. Additionally, tear intensity was varied in three equal increments per condition by blending between tearless and tearful faces of each character. As tears have been shown to be recognized very easily and preattentively (Balsters et al., 2013), this manipulation aimed to increase the number of different tears as well as to render the hypotheses about pupil size more difficult to guess. Finally, all four conditions included an equal number of tearless control stimuli to test within-subjects effects of tear presence (Figure 1).

Each of the 12 faces was shown for 10 s before participants were asked for their ratings of 10 questions using 9-point Likert-type scales displayed directly below the image. All questions were selected randomized sequence using scale anchors of *I completely disagree* (1) to *I completely agree* (9). Three questions were included to assess the main social and signaling functions believed to be associated with sadness and tears ("This face looks sad"; "To look at this face makes me feel sad"; and "If I could, I would like to help her feel better").

Six additional questions aimed to explore specific aspects of warmth and competence inspired by the general Stereotype Content Model (de Ven et al., 2017; Fiske, Cuddy, & Glick, 2007) as well as the possibility of an association between tears and other emotions (Reed, Deutchman, & Schmidt, 2015). The first four questions aimed to capture warmth of the face (This face looks warm), warmth as a personal competence (This person looks capable of feeling empathy), emotional competence in the sense of being able to experience emotions (This person looks capable of experiencing emotions), and emotional competence as being capable of self-control (This person looks capable of self-control). As shown by de Ven et al. (2016), tearful individuals are generally seen as warmer but also as generally less competent. More specifically, the sense of powerlessness postulated to be associated with crying (Vingerhoets, 2013) should conversely result in a perceived lack of emotional self-control. Since the present study used avatars rather than photographs, the addition of tears might add to their emotional believability (de Melo & Gratch, 2009). Finally, items for happiness and shame were included as potential candidates of other emotional states potentially associated with tears (Reed et al., 2015). Attractiveness was included as a control item.

Results

To examine the effects of tears and pupil size, first a mixed multivariate repeated measures analysis of variance was conducted with tear presence (tears, no tears) as the repeated factor, and tear intensity (low, high) and pupil size[1] (small, large) as the between-subjects factors.[2] For the dependent variables, this analysis included the 3 social signaling items (perceived sadness, felt sadness, and wish to help), the 6 additional items (warmth, emotions, empathy, self-control, happiness, shame), and the control variable (attractiveness). No significant interactions were found (all p values $> .2$). However, significant main effects were observed for tear presence, $F(10, 37) = 3.96$, $p < .001$, $\eta_p^2 = .517$, and pupil size, $F(10, 37) = 2.39$, $p = .027$, $\eta_p^2 = .392$. This suggests that the addition of tears had a substantial effect, whereas the variation of tear intensity did not result in any significant effects[3] ($p = .197$, $\eta_p^2 = .282$). Tear intensity was thus excluded from all subsequent analyses.

Tears

As shown by univariate analyses of tear presence[4] (Table 1), tearful faces were perceived as sadder, $F(1, 46) = 27.72$, $p < .001$, $\eta_p^2 = .376$, and elicited greater self-reported sadness, $F(1, 46) = 13.23$, $p < .001$, $\eta_p^2 = .223$, as well as a greater wish to help, $F(1, 46) = 6.88$, $p = .012$, $\eta_p^2 = .130$. These findings were overall consistent with prior results from studies that used photographs (Hendriks & Vingerhoets, 2006). In addition, avatars of faces with tears were perceived as more capable of emotional experience, $F(1, 46) = 11.38$, $p = .002$, $\eta_p^2 = .198$, yet simultaneously as less capable of self-control, $F(1, 46) = 11.38$, $p < .001$, $\eta_p^2 = .216$. Finally, the addition of tears was associated with a significant reduction of perceived happiness in tearful ($M_{\text{tearful}} = 2.55$, $SD = 1.22$) compared to tearless faces ($M_{\text{tearless}} = 3.13$, $SD = 1.52$, $p = .007$), a finding that did not appear to reflect a simple inverse of sadness.[5] Additional results suggesting a possible increase of perceived shame and a greater capacity for empathy failed to remain significant following Bonferroni correction (cf. Table 1 for complete results).

While the finding of an increased wish to help was consistent with expectations from the literature, the question remains if perceiving and feeling sadness might be important intermediate steps that could help to explain the increased wish to help a crying person. To examine the roles of perceived and felt sadness, mediation analyses were conducted using *MEMORE* (V1.1; Montoya & Hayes, 2017) for SPSS. *MEMORE* uses the bootstrapping method (Preacher & Hayes, 2008) adapted for within-subject designs (Montoya & Hayes, 2017). Ninety-five percent confidence intervals were generated from 10,000 bootstrap samples and are reported in brackets.

First, felt and perceived sadness were entered as potential parallel mediators. The indirect effect of perceived sadness was not significant ($a_1b_1 = .03$ [$-.33$, .39]). However, the indirect effect of felt sadness, controlling for tear presence and perceived tears, was significant (felt sadness, $a_2b_2 = .47$

Table 1. Univariate Effects of Tear Presence.

Question	No Tears		Tears Present				
	M	SD	M	SD	F(1,46)	p	η_p^2
Functions[a]							
This face looks sad	5.30	1.72	6.52	0.96	27.716	<.001	.376
To look at this face makes me feel sad	4.32	1.98	5.11	1.63	13.234	<.001	.223
If I could, I would like to help her feel better	5.77	1.74	6.32	1.39	6.881	.012	.130
Stereotypes and other emotions[b]							
This face looks warm	5.07	1.71	4.88	1.42	.619	.436	.013
This person looks capable of experiencing emotions	6.09	1.41	6.68	0.96	11.378	.002	.198
This person looks capable of feeling empathy	5.71	1.47	6.16	0.86	4.342	.043	.086
This person looks capable of self-control	6.14	1.50	5.34	0.93	12.666	<.001	.216
This face looks happy	3.13	1.52	2.55	1.22	8.095	.007	.150
This face looks ashamed (shows shame)	3.59	1.68	4.10	1.50	5.016	.030	.098
Control item[a]							
This face looks attractive	5.63	1.65	5.37	1.41	2.188	.146	.045

[a]Dependent variables tested without type I error correction. [b]Dependent variables tested with Bonferroni correction for six statistical tests ($\alpha = .0083$).

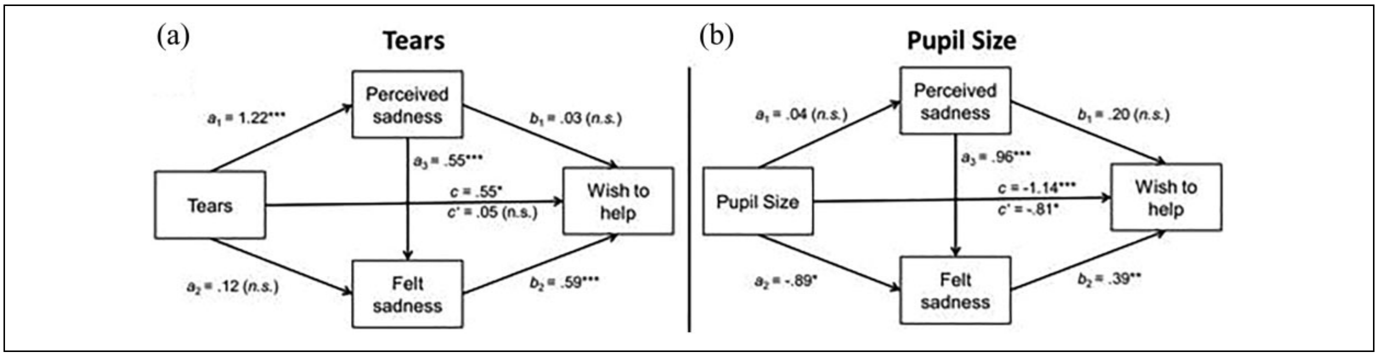

Figure 2. (a) Serial within-subject mediation analysis (left panel; Montoya & Hayes, 2017) of the presence or absence of a tear on wish to help via perceived sadness, and then felt sadness reported by participants. (b) Serial between-subjects mediation analysis (Hayes, 2012) of the effect of small or large pupils on wish to help via perceived sadness (of the face) and then felt sadness reported by participants. The direct effect of the tear manipulation is indicated as c, and the direct effect when controlling for the serial mediation as c'. Numbers reflect unstandardized regression weights. *$p < .05$; ***$p < .001$; $N = 50$.

[.14, .95]), suggesting a mediation by felt sadness.[6] Furthermore, the direct effect of tears on wish to help was no longer significant after addition of the mediators ($c = .55$ [.13, .97], $p = .01$; $c' = .05$ [−.43, .53], $p = .83$), a finding consistent with the traditional view of a full mediation (Baron & Kenny, 1986). However, even if perceived sadness does not directly mediate the wish to help, it might still play a role in this process when considering the possibility that felt sadness might itself be mediated by perceived sadness. To account for this possibility, the analysis was repeated with option of a serial mediation via perceived sadness and then felt sadness (Figure 2, Panel a). In this model, neither of the individual indirect effects remained significant after controlling for serial mediation (perceived sadness, $a_1b_1 = .03$ [−.33, .39]; felt sadness, $a_2b_2 = .07$ [−.19, .33]). Instead, the indirect effect of the serial mediation was indeed significant (serial effect, $a_1a_3b_2 = .40$ [.11, .86]), consistent with a serial mediation via perceived sadness followed by felt sadness.

Pupils

Following Harrison et al. (2006, 2007), small pupils were hypothesized to elicit more intense sadness and more empathic responses from observers. We, therefore, followed the multivariate effect of pupil size by univariate comparisons for perceived sadness, sadness felt by the participant, and the wish to help the participant feel better. For the purposes of this analysis, accounting for the absence of any pupil-size effects for neutral faces observed by Harrison et al. (2006), all neutral tearless faces were excluded and treated as distractor items. Contrary to our prediction, pupil size showed no significant effect on perceived sadness, $F(1, 46) = 0.06$, $p = .80$, $\eta_p^2 = .001$. However, smaller pupils made participants feel more sad, $F(1, 46) = 5.39$, $p = .025$, $\eta_p^2 = .101$, and elicited a significantly greater wish to help,[7] $F(1, 46) = 13.00$, $p < .001$, $\eta_p^2 = .213$ (Figure 3).

A serial mediation analysis was conducted with PROCESS (V2.16.3; Hayes, 2012, 2013) to examine to what extent small

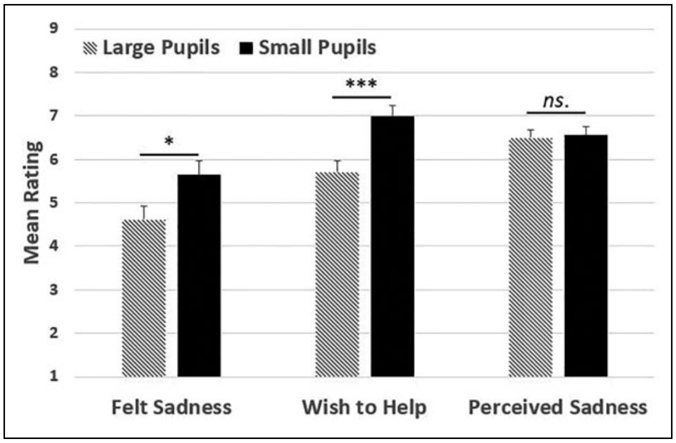

Figure 3. Mean felt sadness, wish to help, and perceived sadness as a function of pupil size. Error bars represent $\pm$ 1 SEM. *Significant difference at p < .05; ***Significant difference at p < .001.

pupils might affect wish to help via perceived and felt sadness in a way comparable to the serial mediation found for tears (Figure 2, Panel b). The indirect effect of perceived sadness was not significant ($a_1b_1 = -.01$ [$-.18$, $-.08$]), but the indirect effect of felt sadness was significant ($a_2b_2 = -.40$ [$-.82$, $-.11$]). The indirect effect of perceived sadness and felt sadness in serial was not significant ($a_1a_3b_2 = -.02$ [$-.24$, .18]). Together, these results suggest that pupil size induced changes in the wish to help a crying person might overall be less affected by conscious perception of sadness than what appears to have been the case for tears.

Realism

All stimuli in this experiment were created based on 3-D models rather than photographs to allow the addition of tears and precise manipulation of pupil size for faces showing a completely neutral expression. To control whether the addition of tears may have resulted in any decrease of perceived realism, participants were shown all faces a second time after conclusion of the main part of the experiment.[8] Responses to three questions concerning perceived realism of the face, the eyes, and the skin were submitted to a repeated measures analysis of variance on tear presence (within-subjects), tear intensity, and pupil size as above. Neither the presence of tears, $F(3, 44) = .79$, $p = .508$, $\eta_p^2 = .051$, nor their intensity $F(3, 44) = .70$, $p = .560$, $\eta_p^2 = .045$, or the size of the pupils, $F(3, 44) = .19$, $p = .900$, $\eta_p^2 = .013$, affected perceived realism, and there were no significant interactions (all ps > .30). Finally, for pictures with tears, the participants evaluated perceived realism and intensity of the tears. Ratings for both questions submitted to a multivariate analysis of variance on tear intensity and pupil size. Again, neither tear intensity, $F(2, 45) = 2.39$, $p = .228$, $\eta_p^2 = .054$, nor pupil size, $p = .336$, $\eta_p^2 = .047$, nor the interaction, $p = .502$, $\eta_p^2 = .030$, reached significance.

General Discussion

The present findings suggest that tears and reduced pupil size affected the extent to which observers reported a wish to help in response to seeing the faces. These effects were mediated by felt sadness for both tears and pupils as well as by perceived and felt sadness in serial when tears were added to the avatars. While the ecological validity of these findings is somewhat limited due to the use of rendered materials rather than photographs, the overall effects for tears were consistent with prior research and showed no evidence for significant differences in perceived realism.

Contrary to expectations, this study found no significant evidence for an amplification of the tearing effect by constricted pupils, as the interaction effects between tears and pupils were not significant. Conversely, this suggests that small pupils may elicit a wish to help as well as feelings of sadness even for highly controlled neutral expressions. Notably, consistent with the findings of Harrison et al. (2007), *perceived* sadness of small pupils with the neutral facial expressions remained virtually unaffected by the manipulation of pupil size. The finding that small pupils were associated with an increased desire to help and felt sadness but not perceived sadness suggests that this type of social signal might function to influence perceivers rather than to convey emotional information about the signaler.

The direction of the effects observed for small pupils was consistent with prior evidence (Harrison et al., 2006, 2007). Furthermore, the present findings may lend initial support to the notion that pupillary regulation in sadness processing might serve to counteract blurred vision caused by emotional tears, that is, help to mitigate the evolutionary handicap of emotional tears suggested by Hasson (2009). Since small pupils appeared to influence the propensity of observers to offer help even in the absence of emotional tears, it seems possible that the experience of intense sadness alone might already be sufficient to elicit such a regulatory pupillary response also in anticipation of imminent tears rather than merely as a purely physiological response to the increase in tear volume experienced during crying. In consequence, future research might investigate if pupil size, indeed, changes in anticipation or in consequence of intense emotional crying. Furthermore, pupillary responses to eye drops may differ from responses to emotional tears not only as a function of their chemical composition but also because of differences in the underlying emotional states.

While some of the limitations of artificially induced, “onion tears” have previously been discussed in the crying literature (e.g., Vingerhoets, 2013), the finding that pupil size may add to the social signaling value of emotional crying suggests that most prior research may still have underestimated the apparent impact of more complete instances of emotional tearing on observers. The common method of manipulating tears in still photographs is very limited in its ability to study the impact of dynamics in emotional tearing, including visible cues such as changes in pupil size, changes in eye blink rates, or an increase of scleral redness as a consequence of prolonged crying. Here, the present study provided some initial evidence for the potential usefulness of generating tears on realistic 3-D models. Building, for example, upon the pioneering work of de Melo and Gratch (2009), realistically animated models of human emotional crying should soon allow testing of crying dynamics, including the shedding of further light on the mechanisms underlying potential evolutionary relationships between emotional tears and pupil constriction.

Although these results are intriguing, the present study still faces certain limitations. First, all stimuli were presented to participants without time constraints. For tears, Balsters, Krahmer, Swerts, and Vingerhoets (2013) have already shown evidence that even very briefly presented tears may be sufficient to facilitate sadness recognition. The mediation analyses conducted on the present data suggest that these effects might be further decomposed as part of reaction time experiments. Second, comparable to previous research by Harrison et al. (2006), the present study only used static images. More recent research in this field has studied precisely timed effects of pupil mimicry, including eye tracking to demonstrate powerful interpersonal effects of changes in pupil size (e.g., Kret et al. 2015). Third, results of the mediation analyses are limited to the extent that they can only present a different statistical look at the data. Further laboratory research with eye tracking and incentivized games might be able to address the issue of dynamics as well as aim to further disentangle the possible mediating interrelationships between tears, pupillary responses, and measurable social helping behavior. Here, the present findings can only be regarded as a starting point. Fourth, the present study did not investigate possible gender effects that could play a role for eliciting social support. For example, in one provocative study, Gelstein et al. (2011) suggested the presence of specific chemosignaling functions of female tears. While these findings, so far, have not been successfully replicated (Gračanin, van Assen, Koraj, & Vingerhoets, 2016), they nevertheless emphasize the need for more attention to be paid to the gender of cryers and participants in the role of observers. Finally, some of the additional results of the present study should be regarded as largely explorative. In comparison to de Ven et al. (2017), who used 4 items to assess warmth, the present study assessed general perceived warmth with only a single item, which failed to replicate the warmth effects of tears found by de Ven and colleagues. It is possible that methodological differences, for example, the addition rather than subtraction of tears might have had an impact on perceived warmth. Nevertheless, the present results raise the possibility that the effects of tears on social stereotyping might be more pronounced for more specific first impressions. For example, tears might be more closely associated with perceived richness of emotional experience, rather than "warmth" per se. Such questions, while intriguing, would still need to be addressed more systematically in additional research.

In conclusion, the present findings lend initial support to the notion that pupil constriction, in line with its likely primary functions to optimize vision, may help to counteract some of the physiological handicapping costs of blurry vision—without negatively impacting the handicapping value of tears as a social signal. This suggests that pupil size changes might be a more subtle signal or cue that may have become associated with a need for social support. The social effects of small pupils observed in the present study generally appear comparable to those of tears, yet they might differ in the extent to which observers become aware of changes in the apparent emotional state of the person in front of them. While further research would be required to test the hypothesis that this kind of pupillary response could help to reduce apparent handicapping costs imposed by tears (see Hasson, 2009), such a trade-off mechanism would be compatible with the principle of other trade-offs that have recently been shown for facial expressions. As demonstrated by Lee, Mirza, Flanagan, and Anderson (2014), the respective narrowing and widening of the eyes associated with certain emotional states might be explained on the basis of such sensitivity-acuity trade-offs. Whether or not pupil mimicry effects in sadness processing might, thus, be related to an actual, or anticipatory, compensation of tear-induced blurred vision, both tears and pupils appear to have acquired social signaling value in these contexts. Accordingly, both mechanisms together might improve reliability of other socioemotional cues and thus help observers to differentiate between apparent emotional states and whether or not they would be expected to offer help.

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ORCID iD

Dennis Küster http://orcid.org/0000-0001-8992-5648

Notes

1. The within-subjects manipulation of pupil size (three levels per between-subjects condition) was analyzed separately in another repeated measures analysis of variance by collapsing over small, medium, and large pupil sizes of each condition. This analysis yielded no significant effects (all p values $> .2$; except for happiness, $p = .124$). The within-subjects manipulation of pupil size was, therefore, excluded from all subsequent analyses.
2. The assumption of sphericity was met because each factor in this design had only two levels. Further, Levene's test showed no differences of error variances.
3. An additional repeated measures analysis of variance was conducted on the within-conditions effects of tear intensity by grouping the low, medium, and high tear intensities, corresponding to their between-subjects conditions (cf. intensity percentages indicated in Figure 1). This analysis showed a marginally significant

linear effect of perceived lesser self-control, $F(1, 49) = 3.85$, $p = .055$, $\eta_p^2 = .073$) for high tear intensity ($M = 4.96$, $SD = 1.59$) compared to medium ($M = 5.50$, $SD = 1.32$) and ($M = 5.50$, $SD = 1.42$) low tear intensity. No other effects in this analysis reached significance (all other p values > .10). Finally, to explore the possibility of a perception threshold for a minimum level of visibility of the tears required to produce a social effect, additional univariate tests were conducted to contrast the between-subjects conditions of 20% and 80% tear intensity. None of these contrasts reached significance (all p values > .15).

4. In accordance with Stevens (2012), the three main dependent variables supported by prior literature were tested without correction at $\alpha = .05$ (cf. Schulz & Grimes, 2005; Streiner & Norman, 2011). Comparisons for the six additional stereotype- and emotion-related variables were made against a Bonferroni-corrected $\alpha = .0083$.
5. Perceived sadness and the inverse of perceived happiness exhibited insufficient internal consistency ($\alpha = .327$) to justify collapsing of both variables into a single scale.
6. As discussed by Montoya and Hayes (2017), the modern path-analytic framework no longer requires c' to be statistically different from zero before one can claim mediation.
7. Supplementary analysis using the same approach but including neutral faces without any tears yielded overall consistent yet somewhat weaker results: perceived sadness: $F(1, 48) = 0.09$, $p = .769$, $\eta_p^2 = .002$; felt sadness: $F(1, 48) = 2.73$, $p = .105$, $\eta_p^2 = .054$; wish to help: $F(1, 48) = 9.30$, $p = .004$, $\eta_p^2 = .162$. These findings are in line with the lack of significant pupil-size effects for neutral facial expressions observed by Harrison et al. (2006).
8. All of these questions used the same kind of 9-point Likert-type scales as in the main experiment.

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