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Threatening pictures induce shortened time-to-contact estimates

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Abstract The ability to estimate the time remaining until collision occurs with an approaching object (time-to-collision, TTC) is crucial for any mobile animal. In the present study, we report three experiments examining whether higher level cognitive factors, represented by affective value of approaching objects, could affect judgments of TTC. A theory of TTC estimates based purely on the optical variable tau does not predict an influence of the affective value of an approaching object. In Experiments 1 and 2, we compared TTC estimates of threatening and neutral pictures that approached our participants on a screen and disappeared from view before a collision would have occurred. Images were taken from the International Affective Picture System. Threatening pictures—in particular, the picture of a frontal attack—were judged to collide earlier than neutral pictures. In Experiment 3, the approaching stimuli were faces with different emotional expressions. TTC tended to be underestimated for angry faces. We discuss these results, considering the roles of affective and cognitive mechanisms modulating TTC estimation and general time perception.

Keywords Time-to-collision · Affective factors · Emotion

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Introduction

Avoiding potentially dangerous moving objects and acquiring desirable ones is crucial for any mobile animal. To do so, it is essential to estimate the time remaining until collision or time-to-collision (TTC). In the present study, we examined the notion that higher level cognitive factors, represented by affective value of approaching objects, could affect judgments of TTC. In previous studies, researchers have demonstrated effects of cognitive processes on TTC judgments and have demonstrated the effect of affective content on perceptual and cognitive processes, but they have not examined the effect of affective content on TTC judgments.

Time-to-contact estimation: just a low-level optical analysis?

The human visual system can guide precisely timed actions. For example, a trained baseball player can, under ideal circumstances, hit a ball in a time window of 2–4 ms (Regan, 1992). Lee's (1976) tau theory assumes that the visual system accomplishes this timing accuracy with a tau processor that calculates the variable tau. Tau is the ratio of the visual angle subtended by the distance between any two points on an object divided by the rate of change of this angle. Tau provides (under several preconditions) an exact measure of TTC without the need to estimate velocities and distances. Neurons that function as tau processors have been found in the pigeon's nucleus rotundus. They are involved in the bird's motor response to objects on a collision course (Wang & Frost, 1992).

TTC estimates purely based on tau would not be influenced by the affective value of an approaching object. However, there are at least two reasons to expect such an effect. First, cognitive factors can affect TTC estimation. These include effects of limits in cognitive processing (DeLucia & Novak, 1997; Novak, 1998), cognitive extrapolation of motion (DeLucia & Liddell, 1998), and cognitive workload (Baurès, Oberfeld, & Hecht, 2010). Indeed, numerous factors other than tau affect TTC judgments in humans (e.g., DeLucia, 1991, 2004, 2005; DeLucia, Tresilian, & Meyer, 2000; DeLucia & Warren, 1994; Hecht & Savelsbergh, 2004; Kerzel, Hecht, & Kim, 1999; Oberfeld & Hecht, 2008). In pigeons, neurons alter their response onset time when global optic flow suggests that the bird is in motion, enabling it to start an evasive maneuver closer to the time of collision and thus making it harder for a predator to counter-react (Xiao & Frost, 2009).

More generally, in previous studies, researchers have demonstrated effects of higher level factors on lower level processes. For example, motion perception — even the putatively low-level aperture problem — can be modulated by attention (DeLucia & Ott, 2011; Raymond, 2000). Such modulation is consistent with projections from cortical pathways to the parts of the brain that process motion (Raymond, 2000).

Second, it has been shown that emotional stimuli can affect cognitive and perceptual processes such as attention (Fenske & Eastwood, 2003; Smith, Cacioppo, Larsen, & Chartrand, 2003), visual search (Öhman, Lundqvist, & Esteves, 2001), spatial information processing (Crawford & Cacioppo, 2002), memory (Bradley, Greenwald, Petry, & Lang, 1992), and even low-level contrast sensitivity (Phelps, Ling, & Carrasco, 2006).

In light of these findings, in the present study we expected to find an effect of affective content on TTC judgments. In previous studies, researchers have not measured potential affective modulation of TTC estimation.

Estimating time-to-contact of threatening stimuli

Any object approaching on a collision course is a potential danger for a vulnerable organism. A wide range of animals (e.g. crabs, frogs, chickens, kittens; Schiff, 1965), including few-weeks-old human infants (Ball & Tronick, 1971; Yonas et al., 1977) show avoidance responses to looming visual stimuli, and people judge the TTC of objects that will hit them shorter than that of objects that will miss them (Gray & Regan, 2006).

The question we pose presently is whether there is a similar difference between threatening and nonthreatening objects that approach on a collision course. After all, we react differently if something soft and harmless is thrown at us as compared with something hard, sharp, or pointy. Simple shapes such as circles, rectangles, or stars do not seem to do the trick: Schiff (1965) found the same avoidance responses to looming stimuli regardless of their shape in several species, including humans. However, his stimuli were very simple geometrical silhouettes, and he noted that his behavioural measures might have been too gross to find any such differences.

The superior colliculus seems to play an important role when deciding whether a novel stimulus calls for an emergency reaction both in rodents (Dean, Redgrave, & Westby, 1989) and humans. In the latter, this brain structure's response to looming stimuli is enhanced as compared with receding or randomly moving stimuli (Billington, Wilkie, Field, & Wann, 2011), and the mere presence of an emotional stimulus, such as a picture of a fearful face, can speed up saccadic eye movements—a reaction thought to be mediated by amygdala-pulvinar-superior colliculus connections (West, Al-Aidroos, Susskind, & Pratt, 2011). In light of such a fast, subcortically processed influence of emotional stimuli on observable behavior, it seems reasonable to expect affective modulation of TTC estimates, even if there were no higher order cognitive processes involved.

Experiments 1 and 2

To investigate whether human TTC estimation is influenced by affective significance, we compared neutral picture objects with threatening ones that showed motives implying immediate danger of getting hurt or killed. We hypothesized that people would judge TTC to be shorter for threatening stimuli than for neutral ones. We also examined whether the presentation duration of the pictures would influence the effect of affective content on TTC estimation, to elucidate the involvement of fast, subcortical mechanisms or slower, cognitive processes.

Method

Nineteen people (mostly students at the University of Mainz), participated in Experiment 1 for course credit or payment (eight men, 11 women; ages 18–47 years, $M = 23.4$; $SD = 6.85$); 20 others participated in Experiment 2 (eight men, 12 women; ages 19–41 years, $M = 24.6$; $SD = 5.48$). All were tested to have normal or corrected-to-normal visual acuity and normal stereovision.

Twelve images from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2005) served as stimuli: a snarling Pit Bull, a masked attacker with a knife, and a biting snake, each labeled with high arousal and low valence and dominance ratings, were compared with nine "neutral" images from the categories "people," "objects," and "plants and mushrooms," each labeled with intermediate to low arousal ratings and intermediate to high valence and dominance ratings in the catalogue.[1] Neutral pictures covered the same range of contrast, depth impression, and spatial frequency patterns as the threatening ones. Original pictures were used in Experiment 1. In Experiment 2, each picture was divided into 48 rectangles and was reassembled in a randomized order to separate the effect of emotional content from low-level image features.

[1] The IAPS numbers of the pictures used were: 1120, 1300, 2070, 2190, 2650, 5000, 5500, 5510, 6510, 7175, 7190, 7330

Displays were presented in stereo on a 2.60 × 1.95 m projection screen at 24 frames/s; participants viewed them using a chin rest from 2 m in a darkened room. In a prediction-motion paradigm, a threatening or neutral picture (affective content) was depicted as approaching the participant through a tunnel at constant velocity and was blanked out after 200 or 800 ms (presentation duration). Participants were instructed to extrapolate the motion of the picture after it disappeared and to press a button when it would have collided with them. Consistent with previous TTC studies (e.g., DeLucia, Kaiser, Bush, Meyer, & Sweet, 2003; McLeod & Ross, 1983) TTC estimates were calculated as the time from the pictures' disappearance to the participant's button press. To discourage participants from making their judgments on the basis of simple heuristics (e.g., a single stimulus property such as image size), we varied picture width (2.0 or 2.2 m), approach velocity (4 or 5 m/s), and actual TTC (time from disappearance to collision: 600, 800, or 1,000 ms). The starting distance for each trial was calculated by multiplying the sum of presentation duration and TTC by approach velocity, and varied accordingly (3.2; 4; 4.8; 5; 5.6; 6; 6.4; 7; 7.2; 8; 9 m). The design was fully crossed, so participants viewed 288 trials (12 pictures × 2 presentation durations × 2 widths × 2 velocities × 3 TTCs) in a randomized order.

In both experiments, after all TTC judgments had been made, we assessed arousal, valence, and dominance ratings with self-assessment manikins (SAMs; Lang, 1980), asking the participants: "How do you feel when you look at this picture?" In Experiment 2, self-reported difficulty to recognize the scrambled picture's content was additionally reported on a 1 (*not recognized at all*) to 6 (*easily recognized*) scale.

Results

TTC estimates are plotted as a function of actual TTC in Fig. 1 (original IAPS) and Fig. 2 (scrambled IAPS). In both experiments, performance was very consistent, reflecting true TTC quite well and showing just small differences between threatening and neutral images. Initial analyses were conducted including all independent experimental factors. TTC estimation errors (TTC estimate – actual TTC) were subjected to a 2 (affective content) × 2 (presentation duration) x 2 (velocity) x 2 (width) x 3 (TTC) repeated measures ANOVA for each experiment.

Slower velocity and larger picture width each led to shorter TTC estimates in both experiments [original pictures, width: $F(1, 18) = 14.3$, $p = .001$, $\eta_p^2 = .443$; original pictures, velocity: $F(1, 18) = 76.1$, $p < .001$, $\eta_p^2 = .809$; scrambled pictures, width: $F(1, 18) = 12.9$, $p = .002$, $\eta_p^2 = .404$; scrambled pictures, velocity: $F(1, 18) = 77.8$, $p < .001$, $\eta_p^2 = .804$]. Such effects of velocity and object size are consistent with previous TTC studies (e.g., Caird & Hancock, 1994; DeLucia, 1991; Smith, Flach, Dittman, & Stanard, 2001). In our study, both effects can be explained by the known size-arrival effect (DeLucia, 1991; DeLucia & Warren, 1994), because faster approach velocity was associated with a smaller image size while the picture was visible, because of the greater starting distance.

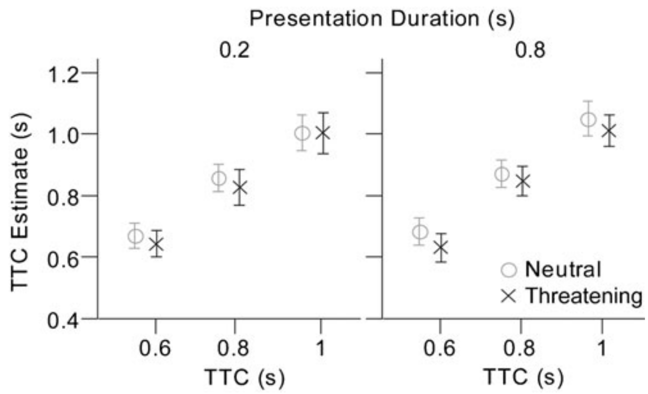

Fig. 1 Average TTC estimates as a function of the actual three TTC values (collapsed over velocity and picture width) for threatening and neutral pictures presented for 200 ms and 800 ms in Experiment 1 (original IAPS). *Error bars* represent standard errors of the means

The main effect of the factor TTC was not significant, probably reflecting the small differences (steps of 200 ms) among the levels of this factor. Interactions among width, velocity, and TTC were not significant except for a five-way interaction among all five independent factors when the pictures were scrambled. Such a five-fold interaction is difficult to interpret, and we do not have enough cases to justly do so. In any case, our main factors of interest were affective content and presentation duration. Thus, we analyzed TTC estimation errors averaged over picture size, velocity, and TTC with a 2 (affective content) × 2 (presentation duration) repeated measures ANOVA for each experiment. Below we present only these analyses; the effects and interactions of affective content and presentation duration found therewith are essentially the

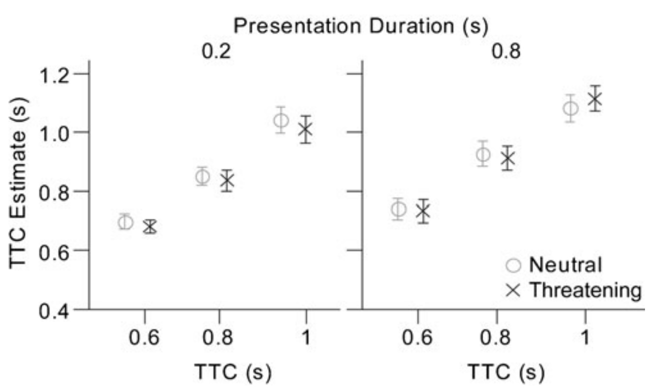

Fig. 2 Average TTC estimates as a function of the three actual TTC values (collapsed over velocity and picture width) for threatening and neutral pictures presented for 200 ms and 800 ms in Experiment 2 (scrambled IAPS). *Error bars* represent standard errors of the means

same as in the full analyses mentioned previously. A comparison of these collapsed TTC estimation errors from Experiment 1 and 2 is shown in Fig. 3.

Analysis of experiment 1 With unscrambled photographs, the average TTC estimate of threatening pictures was 30 ms earlier than that of neutral pictures, $F(1, 18) = 5.16$, $p = .036$, $\eta_p^2 = .223$. There was no significant effect of presentation duration, $F(1, 18) = .470$, $p = .502$, $\eta_p^2 = .025$, and no interaction between presentation duration and affective content, $F(1, 18) = 1.398$, $p = .252$, $\eta_p^2 = .072$.

Analysis of experiment 2 With scrambled pictures, there was no significant effect of affective content, $F(1, 19) = 1.972$, $p = .176$, $\eta_p^2 = .094$. Average TTC estimates were significantly later when presentation duration was longer, $F(1, 19) = 11.188$, $p = .003$, $\eta_p^2 = .371$. The interaction between presentation duration and affective content was just below significance, $F(1, 19) = 4.259$, $p = .053$, $\eta_p^2 = .183$.

Combined analysis of experiments 1 and 2 We compared the results of Experiments 1 and 2 in a 2 (affective content) × 2 (presentation duration) x 2 (experiment) ANOVA. In this combined analysis, TTC estimates were significantly earlier with threatening pictures, $F(1, 37) = 7.255$, $p = .011$, $\eta_p^2 = .164$, and significantly later at the longer presentation duration, $F(1, 37) = 7.774$, $p = .008$, $\eta_p^2 = .174$. There was a significant interaction among affective content, presentation duration, and experiment, $F(1, 37) = 4.867$, $p = .034$, $\eta_p^2 = .116$. Four separate paired-samples *t* tests, one for each presentation duration in each experiment, indicated that TTC estimates were 39 ms shorter for threatening pictures than for neutral ones, but only with original pictures at the longer presentation duration (see Table 1).

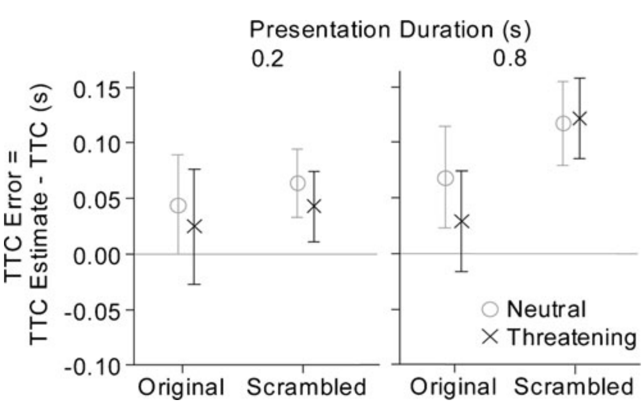

Fig. 3 Average TTC estimation errors (collapsed over actual TTC, velocity, and picture width) for threatening and neutral pictures presented for 200 ms and 800 ms combined for Experiment 1 (original IAPS) and Experiment 2 (scrambled IAPS). *Error bars* represent standard errors of the means

The interaction between presentation duration and experiment was not significant, $F(1, 37) = 3.189$, $p = .082$, $\eta_p^2 = .079$; there was no significant main effect of the factor experiment and no other significant interaction (all *F*s < 2.3; all *p*s > .1).

SAMs ratings (see Table 2) were analyed with 2 (affective content) x 2 (experiment) ANOVAs. Threatening pictures received higher arousal ratings, $F(1, 37) = 193.6$, $p < .001$, $\eta_p^2 = .840$, and lower valence ratings, $F(1, 37) = 154.7$, $p < .001$, $\eta_p^2 = .807$, than did neutral ones in both experiments, but differences between threatening and neutral pictures were rated smaller when the images were scrambled (significant interactions between affective content and experiment for arousal, $F(1, 37) = 20.722$, $p < .001$, $\eta_p^2 = .359$, and valence, $F(1, 37) = 6.557$, $p = .015$, $\eta_p^2 = .151$.

Finally, scrambled threatening pictures ($M = 3.23$; $SD = 1.47$) were neither harder nor easier to recognize than neutral ones ($M = 3.16$; $SD = 1.09$; $t(19) = .299$, $p = .768$).

Discussion

The effect of emotion exists, but it is rather small. It is also limited to long presentation times and to intact pictures. Only at longer presentation times were the unscrambled threatening pictures associated with shorter TTC compared to the scrambled pictures or the unscrambled neutral pictures. Thus, the cognitive significance associated with the picture rather than the immediate affect appears to influence TTC estimation. In addition, a rather coarse scrambling was sufficient to eliminate the effect of affective content on TTC estimates.

In conclusion, the results of Experiments 1 and 2 indicated that threatening pictures of frontal attacks shortened TTC estimates. Potentially threatening objects were judged to collide earlier only when given time to process this information.

Experiment 3

We examined whether an emotional facial expression by itself would have the same effect as the threatening gesture. Will the effect of the negative affective content presented by threatening situations generalize to negative emotions (anger) expressed on human faces? We expected such an effect on the basis of Öhman et al.'s (2001) finding that visual search for discrepant faces among a matrix of faces was faster and more accurate when the discrepant face was threatening, as compared with friendly. Thus, we replicated Experiment 1 with pictures of facial expressions instead of the IAPS pictures.

Table 1 *t* test results comparing TTC estimation errors of neutral and threatening pictures from Experiments 1 and 2

	TTC Estimate Difference Threatening – Neutral (ms)					
Experiment	Presentation Duration (ms)	*M*	*SD*	*Paired t*	*df*	*p*
Original pictures	200	-20	78	-1.110	18	.282
Original pictures	800	-39	54	-3.177	18	.005*
Scrambled pictures	200	-21	44	-2.164	19	.043
Scrambled pictures	800	5	32	.642	19	.529

* Significant after Bonferroni correction of alpha level from .05 to .0125

Method

Twenty people (mostly students at the University of Mainz), participated in Experiment 3 for course credit or payment (four men, 16 women; ages 19–53 years, $M = 25.6$; $SD = 7.36$). The same methods and apparatus from Experiment 1 were used, except that the approaching stimuli consisted of angry, happy, and neutral facial stimuli from the NimStim Set of Facial Expressions (Tottenham et al., 2009). Two different model faces were included (Tottenham et al., 2009; models 20 and 23, open-mouthed version)[2] in addition to an "empty" face with all facial features erased.

Results

Again, performance was very consistent, reflecting true TTC quite well, and showing just small differences between the emotional facial expressions (see Fig. 4). As in Experiments 1 and 2, TTC estimation errors were collapsed across TTC, velocity, and width. These collapsed TTC estimation errors are shown in Fig. 5. They were analyzed with a 2 (presentation duration) × 4 (emotion) repeated measures ANOVA. The main effect of emotion was significant but small, $F(3, 57) = 4.150$, $p = .010$, $\eta_p^2 = .179$, and longer presentation duration resulted in longer TTC estimates, $F(1, 19) = 5.619$, $p = .028$, $\eta_p^2 = .228$. The interaction between emotion and presentation time was not significant, $F(3, 57) = .353$, $p = .787$, $\eta_p^2 = .018$. *t*-tests revealed that only the (artificial) empty face was judged to arrive significantly earlier than the (natural) friendly face (see Table 3), although TTC estimates of the angry face, too, appear shorter than those of the neutral and happy faces (see Fig. 5).

Given the small effect size of emotion, we suspected that our power was insufficient. And since some participants described the empty face as the most disturbing one—even though this is not reflected in the SAM ratings (see Table 2)—we also suspected that the effect of this artificial face masked the effects of the natural emotional expressions. Thus, we reanalyzed the data from Experiment 3, omitting the empty face and using a 2 (presentation duration) × 2 (emotion) repeated measures ANOVA. On the basis of their SAM ratings, especially the equally low arousal ratings, we combined TTC estimation errors from the neutral and happy face and compared this average to that of the angry face. Results showed a significant main effect of emotion, $F(1, 19) = 4.81$, $p = .041$, $\eta_p^2 = .202$, whereas the effect of presentation duration was still significant, $F(1, 19) = 6.32$, $p = .021$, $\eta_p^2 = .250$, and the interaction of emotion and presentation duration was not, $F(1, 19) = 1.17$, $p = .293$, $\eta_p^2 = .058$.

In addition, we ran a combined analysis of TTC estimation errors from Experiment 1 and 3 in a 2 (affective content) × 2 (presentation duration) x 2 (experiment) ANOVA with repeated measures on the first two factors. We again derived a two-leveled factor of affective content from the facial expressions by averaging TTC estimation errors of friendly and neutral faces and comparing this average with the one of the angry faces. In this combined analysis, TTC estimates were significantly earlier with threatening pictures (IAPS attacks and angry faces pooled together against all "neutral"), $F(1, 37) = 9.41$, $p = .004$, $\eta_p^2 = .203$, and were significantly later at the longer presentation duration, $F(1, 37) = 4.94$, $p = .032$, $\eta_p^2 = .118$. There was no significant main effect of the factor experiment and no significant

Table 2 SAM ratings for IAPS pictures in Experiment 1 (neutral and threatening originals), Experiment 2 (neutral and threatening scrambled pictures), and Experiment 3 (facial expressions)

	Arousal Rating		Valence Rating		Dominance Rating	
	1 = calm		*1 = unhappy*		*1 = dominated*	
	9 = excited		*9 = happy*		*9 = dominant*	
Picture Type	*M*	*SD*	*M*	*SD*	*M*	*SD*
Neutral Originals	3.42	1.26	5.98	.69	5.38	1.12
Threatening Originals	7.16	1.39	2.89	.93	3.86	1.86
Neutral Scrambled	4.19	1.05	5.70	.64	5.61	1.23
Threatening Scrambled	6.08	1.24	3.67	1.37	4.13	1.72
Neutral Faces	3.08	1.35	4.58	.94	5.23	1.33
Happy Faces	2.95	1.64	7.15	.86	5.40	1.33
Angry Faces	5.93	1.61	2.73	.85	3.63	1.55
Empty Faces	3.48	1.77	4.58	1.13	5.35	1.51

[2] The facial stimuli were obtained through the Research Network on Early Experiences and Brain Development website, http://www.macbrain.org/resources.htm.

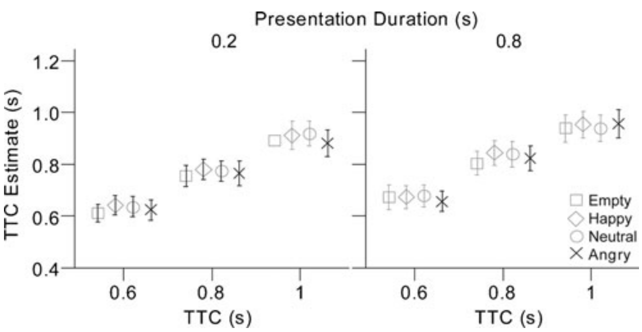

Fig. 4 Mean TTC estimates as a function of the actual TTC values (collapsed over velocity and picture width) for pictures of facial expressions presented for 200 ms and 800 ms in Experiment 3. *Error bars* represent standard errors of the means

Table 3 *t* test results comparing TTC estimation errors of facial expressions from Experiment 3

Pair of Facial Expressions	TTC Estimate Difference (ms)				
	M	*SD*	*Paired t*	*df*	*p*
Empty - Friendly	-22	30	-3.280	19	.004*
Empty - Angry	-6	38	-0.740	19	.468
Empty - Neutral	-20	31	-2.798	19	.011
Friendly - Angry	16	28	2.556	19	.019
Friendly - Neutral	3	30	0.394	19	.698
Angry - Neutral	-13	38	-1.566	19	.134

* significant after Bonferroni correction of alpha-level from .05 to .0083

interaction (all *F*s < 2.6; all *p*s > .1). These results suggest that angry faces had similar effects as threatening pictures.

The angry face was emotionally most different from the three other types as indicated by the SAM ratings (see Table 2). A comparison of SAM ratings for angry faces with those for the threatening IAPS pictures from Experiments 1 and 2 indicated that unscrambled threatening IAPS pictures resulted in significantly higher arousal ratings than did the angry faces, $t(37) = 2.553$, $p = .015$.

Discussion

The face stimuli displaying anger were associated with shorter judged TTCs. This effect seems to be even smaller than that found before for the threatening IAPS pictures. There is no statistical evidence for this difference between angry faces and attack pictures; however, the lower arousal ratings for angry faces, as compared with the threatening IAPS pictures, would be in agreement with this notion. Further study will have to tell whether the emotion expressed in the face carries less weight in influencing TTC judgments than the picture of a threatening situation. Facial expression also appears to be processed more quickly. The effect does not take long presentation times to surface. Thus, the effect of the attack pictures was less immediate and more likely to be cognitively mediated than the effect of the emotional expression.

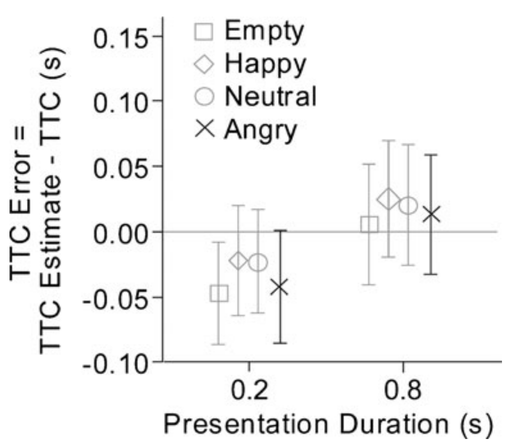

Fig. 5 Mean TTC estimation errors (collapsed over actual TTC, velocity, and picture width) for pictures of facial expressions presented for 200 ms and 800 ms in Experiment 3. *Error bars* represent standard errors of the means

General discussion

We found that TTC was judged on average 30 ms shorter for threatening pictures representing frontal attacks than for neutral pictures (Experiments 1 and 2). This effect was most pronounced with comparatively long presentation times and is thus consistent with previous demonstrations that higher level cognitive factors can influence lower level processes. The emotional valence of facial stimuli, which is processed faster, also had an effect on TTC judgments (Experiment 3). The putatively weaker effect of facial expression may be due to lower arousal, as indicated by the SAM ratings. It remains to be tested whether the effect of facial expression is reliably smaller than that of frontal attack pictures. Recent findings emphasizing the importance of context as a modulating factor for effects of emotion would certainly support this prediction (see Barrett, Mesquita, & Gendron, 2011).

Common sense tells us that the utility of processing facial emotions may be different than that of processing immediate threat. For example, facial expressions allow us to quickly register a threatening face in a crowd or to receive a quick evaluation of whether a person's intentions are positive or negative. The evaluation of whether or not the stimulus does in fact pose a threat involves a cognitive assessment that takes time to process. Other than for attack pictures, we found the effect of facial expression both with shorter and longer presentation times. Thus, there are two interpretation consistent with our data. First, the emotion-guided process should be very fast and independent of more time-demanding cognitive evaluation. Second, angry faces could just not provide the same level of arousal as pictures of attacks, while both are being processed in the same fashion.

An affective or cognitive mechanism?

Pictures of angry faces—though capable of eliciting a freeze-like response in humans (Roelofs, Hagenaars, & Stins, 2010)—imply a form of more ambiguous and less existential threat than do pictures of frontal attacks. Lower arousal ratings of angry faces than of attacks in Experiment 1 reflect this relationship. Interestingly, scrambled attack pictures in Experiment 2 induced approximately the same arousal ratings as angry faces (see Table 2). Whereas participants reported intermediate difficulty to recognize the scrambled pictures' content, scrambling apparently could not eliminate some arousing effects of small-scale image details. The weaker arousing effects of scrambled attack pictures make them comparable to the emotion carried by angry faces. Both seem to lead to a small underestimation of TTC, and, more importantly, both do not benefit from longer presentation times.

The strongest argument for cognitive processing between affective reaction and TTC judgment is carried by our finding that the shortening of TTC estimates of unscrambled attack pictures was most pronounced at the longer presentation duration of 800 ms (see Fig. 3). The data of Experiment 1 show that the shorter presentation duration of 200 ms provided enough time to pick up sufficient information to perform the prediction-motion task at optimum accuracy. The condition with 800-ms presentation duration did not improve judgements; to the contrary, it allowed time for the small bias to enter. The 200-ms duration should also have been enough time to discriminate the emotional content of the pictures (cf. Junghöfer, Bradley, Elbert, & Lang, 2001, and West, Anderson, Ferber, & Pratt, 2011). Apparently it sufficed for a weak influence on TTC estimation based on a first quick (and unconscious) reaction to small-scale image features. The visual system can detect and categorize threatening versus nonthreatening image features and automatically allocate attention without conscious perception of the threat (Lin, Murray, and Boynton, 2009). When the images were visible for 800 ms, there was room for more elaborate cognitive processing. This interpretation would suggest that the TTC estimates for original attack pictures were influenced by the fast emotional evaluation as well as by the slower cognitive evaluation. In the scrambled pictures, however, the initial emotional reaction to threatening small-scale features was overridden by a later conscious perception signaling no threat, because the image was not identifiable. In addition, TTC estimates were later for all scrambled IAPS pictures and all face pictures in Experiment 3 at the longer presentation duration.

Thus far, our interpretations rest on the assumption that the threatening pictures, per se, were perceived to have shorter TTCs. However, an anonymous reviewer noted that the existence of threatening pictures might have a general effect on cognition resulting in earlier perceived TTCs for all objects on collision courses. This alternative interpretation is plausible but was not addressed in our present study and requires further tests. In conclusion, TTC estimation seems to be influenced both by fast, bottom-up affective processes as well as by slow, top-down cognitive processes.

Just an effect on attention and reaction time?

Shorter TTC estimates of threatening pictures could result from faster reaction times RTs) in the presence of more arousing stimuli. Emotion affects attentional processes such as focused attention and visual search (Öhman et al., 2001), and low-level visual processes such as contrast sensitivity (Phelps et al., 2006). Even when labels such as "peaceful" and "hostile" are merely conditioned to pictures of neutral faces, they can lead to slower or faster visual search results (Gerritsen, Frischen, Blake, Smilek, & Eastwood, 2008). Interestingly, and opposite of these findings, an approach reaction (executed with a joystick) to happy faces is faster than an avoidance reaction to angry faces (Nikitin & Freund, 2010).

In our present study, however, TTC values always exceeded the necessary RTs; participants always had at least 600 ms of motion extrapolation after the image disappeared from view, whereas the average RT to a visual stimulus is below 250 ms (Galton, 1899). In addition, the pattern of results from Experiments 1 and 2 speaks against RT modulation as an explanation: The shortening of TTC estimates for attack pictures was more pronounced at the longer presentation duration, when the influence of an RT advantage of threatening pictures should have been smaller.

Just an effect on general time perception?

Another explanation for shorter TTC estimates of threatening pictures is altered general time perception. There are demonstrations of overestimation of time intervals when viewing fear-inducing IAPS images (Grommet, Droit-Volet, Gil, Hemmes, Baker, & Brown, 2011), and angry faces (Gil & Droit-Volet, 2011) as compared with neutral ones. In the latter case, relative overestimation was actually a reduced underestimation of the intervals and thus was closer to the real time spent viewing the stimuli.

A reduced underestimation of the viewing time of pictures with a negative valence as compared with pictures with a positive valence was especially shown for highly arousing pictures, whereas the opposite effect was found for less arousing pictures (Angrilli, Cherubini, Pavese, & Manfredini, 1997). Angrilli et al. attributed this high arousal effect to a subcortical pathway that is quickly activated by threat signals without having full information about the stimuli at hand. The responses of this fast system can later be corrected by a slower, cortical pathway that processes more stimulus information. The explanation of a fast and a slow mechanism responsible for different emotional effects on time perception depending on the time span fits well to our own interpretation of the TTC estimates at shorter and longer presentation durations.

It is conceivable that the threatening stimulus biases the TTC estimate to edge out some time to prepare for a response, or the stimulus could merely speed up the internal clock, which is an arousal-induced acceleration of the biological clock itself (cf. Gil & Droit-Volet, 2011). Alternatively, time intervals filled with threatening stimuli may feel longer because of a reduced latency of an attention-controlled switch (needed to start counting pulses from the internal biological clock). Accordingly, TTC estimates of threatening stimuli would be shorter because of altered time perception rather than a cognitive processing of the stimulus content.

Conclusion

We found shortened TTC estimates for approaching threatening IAPS pictures. However, a rather long stimulus presentation time (800 ms) was necessary for this effect to surface. A faster effect occurred with angry faces. Whereas TTC estimation has long been thought to be a low-level process based on the analysis of simple optical parameters in the retinal image, our results expand the growing evidence for cognitive factors influencing this process by the dimension of affective factors.

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