Safety Strategies in Time-to-Contact Estimation

Inauguraldissertation

Zur Erlangung des Akademischen Grades

eines Dr. phil.,

vorgelegt dem Fachbereich 02 – Sozialwissenschaften, Medien und Sport

der Johannes Gutenberg-Universität

Mainz

von

Esther Simone Brendel

aus Wetzlar

Mainz

2018

Tag des Prüfungskolloquiums: 13. Juni 2018

1 ABSTRACT

English: The ability to estimate the time remaining until collision occurs with an approaching object (time-to-collision, TTC) is crucial for any mobile animal. The purpose of this study was to examine whether there are safety strategies at work in TTC estimation either in the case of threatening stimulus content or in the case of impaired visual conditions. In thirteen Experiments, we compared TTC estimates of simulated objects (mostly pictures) that approached our participants on a screen and disappeared from view before a collision would have occurred. TTC of neutral pictures was usually overestimated whereas threatening pictures (e.g. frontal attacks, spiders) were judged to collide earlier in most cases. This effect was modulated by arousal and fear of spiders. The effects of impaired visual conditions were less conclusive. This study adds to the growing literature that shows how visual perception is influenced by context in its broadest sense, including the semantic meaning of a stimulus and emotional reactions in combination with individual traits of the observer.

Deutsch: Die Fähigkeit, die Zeit bis zur Kollision mit einem sich nähernden Objekt einzuschätzen (Kontaktzeitschätzung), ist für mobile Lebewesen sehr wichtig. Diese Arbeit untersucht, ob Sicherheitsstrategien bei der Kontaktzeitschätzung eine Rolle spielen, zum Einen im Falle bedrohlicher Stimuli, zum Anderen im Falle eingeschränkter Sichtbedingungen. In dreizehn Experimenten verglichen wir die Kontaktzeitschätzungen von simulierten Objekten (meist Bildern), die sich auf einem Bildschirm oder einer großen Leinwand auf unsere Probanden zu bewegten und ausgeblendet wurden, ehe eine Kollision stattgefunden hätte. Die Kontaktzeit neutraler Bilder wurde üblicherweise überschätzt, die von bedrohlichen Bildern (z.B. frontale Angriffe, Spinnen) wurde meist kürzer eingeschätzt. Dieser Effekt wurde durch Erregung und Spinnenangst moduliert. Eingeschränkte Sichtbedingungen hatten weniger aufschlussreiche Effekte. Diese Arbeit erweitert die zunehmende Literatur, die zeigt, dass visuelle Wahrnehmung vom Kontext im weitesten Sinne beeinflusst wird, was sogar die semantische Bedeutung des Stimulus und affektive Reaktionen in Kombination mit individuellen Eigenschaften eines Beobachters einschließt.

2 ACKNOWLEDGMENTS

3   TABLE OF CONTENTS

4   LIST OF TABLES

5 LIST OF FIGURES

6 ABBREVIATIONS

fMRI   functional magnetic resonance imaging

IAPS   International Affective Picture System

PM   prediction-motion

SAM   self-assessment-manikin

SCR   skin conductance response

TTC   time-to-collision

7 INTRODUCTION

Safety strategies are a quite probable result of evolution. In its broadest sense, the term "safety strategy" can refer to anything that enhances an organism's chance of survival, ranging from redundancies and repair mechanisms on a molecular level up to complex cognitive decisions of a highly developed brain. In a more psychological sense, it can mean any kind of connection or process in the nervous system that alters perception and action of an organism in a way that enhances the organism's chance of survival or integrity. In perception, such a safety strategy could also be called a safety bias.

This study is concerned with safety strategies in the visual system, specifically in one definite function of the visual system: the perception of an approaching object's time-to-collision (TTC). I hypothesized to find safety strategies, such as built-in biases or safety margins, that influence the perception of TTC, enhancing the probability of successful interception or avoidance reactions.

7.1 Estimating TTC

Fast, built-in survival circuits in the perception-action loop are very probable to evolve quickly as soon as the nervous system of any species is complex enough to afford them. Gibson's ecological approach to vision (Gibson, 1958/1998, 1966, 1979) provides a theoretical framework of the information available in the visual input and how it could be used by animals to guide their movements. A directly approaching object (called a "looming" stimulus) – in contrast to some other types of motion perception involving impending collisions, like frontoparallel collisions of two objects – is a prominent example of a visual stimulus that has strong and obvious affordances (Gibson, 1979) associated with it, the most typical actions afforded by a looming stimulus being interception, defense, and evasion (compare Field & Wann, 2005, p. 456).

Looming stimuli have been shown to elicit quick responses in several species (Schiff, 1965; Yilmaz & Meister, 2013), including adult (King, Dykeman, Redgrave, & Dean, 1992) and few-weeks-old human infants (Ball & Tronick, 1971; Yonas et al., 1977). In insects, there exist escape responses old and reliable enough that the behavior of insectivorous birds could adapt to exploit them for hunting (Jabłoński & Strausfeld, 2000).

Some aspects of the looming stimulus, most notably the two independent optical variables visual angle and expansion rate of that angle, allow the computation – or at least a practical approximation – of TTC, and thus allow an organism with a visual system to react adequately to impending collisions (e.g. Flach, Smith, Stanard, & Dittman, 2004). Tau, which is the ratio of the visual angle divided by the rate of change of this angle, is one popular variable proposed to be used in the control of action in the context of impending collisions (Lee, 1976).

I will not go into the details of which neurophysiological substrate or which abstract kind of processor, meaning which optical variable, is used in which kind of task. Besides the classical tau, there are plenty of optical variables discussed (for a discussion see Stewart, Cudworth, & Lishman, 1993; Stewart, Cudworth, & Lishman, 1997; Tresilian, 1997, several suggestions of optical variables have been proposed and reviewed by Tresilian, 1999, who concluded that the use of visual information for TTC estimation is very task- and situation-dependent).

Several actual neurons have been detected in animals, signaling various kinds of relevant variables, for example in pigeons (Frost, 2010; Liu, Niu, & Wang, 2008). Within one class of the pigeon's TTC-signaling neurons, the tau-neurons, there are various different TTC values at which different individual cells start firing, each consistently with its own threshold value (Frost, 2010, p. 223). Such variety of signals provides a perfect basis for a safety mechanism to select any value or variable fitting to the actual task and circumstances. As an example, again from the pigeon, the firing of certain TTC-signaling neurons in the pigeon is correlated with flight muscle activity (Wang & Frost, 1992), and certain looming-sensitive neurons alter their response depending on the optic flow in the bird's visual field, as if delaying the bird's escape maneuver when it is already in flight, and thus giving an approaching predator less time to react to the evasion (Xiao & Frost, 2009).

Even though there seems to be a link between estimating TTC and the activation of brain regions that are responsible for motor preparation and control in humans (Billington, Wilkie, Field, & Wann, 2011; Coull, Vidal, Goulon, Nazarian, & Craig, 2010; Field & Wann, 2005), there is also a lot of evidence that humans do not simply rely on tau neurons, if such neurons exist: Their estimates depend on cognitive factors like cognitive extrapolation of motion (DeLucia & Liddell, 1998), especially in a prediction-motion paradigm which leaves much room for cognitive modulation during post-perceptual processing (Tresilian, 1995, 1999). Strengthening this view, TTC estimates are less accurate above values

of 2-3 s actual TTC, giving room for more individual differences with an increasing involvement of cognitive extrapolation (Schiff & Oldak, 1990).

In addition, perceptual learning seems to play an important role: Blind observers are as good in acoustic TTC estimation as sighted observers are in visual TTC estimation (Schiff & Oldak, 1990, p. 307). Thus, an individual brain apparently has to learn which neurons, tau processors or others, and which following adaptations and computations of their output are best utilized, depending on the task, the stimulus and the situation at hand.

7.2   Safety strategies in estimating TTC

Safety strategies in TTC estimation have been proposed earlier, for example named cue switching and immediacy bias (Rushton & Wann, 1999, p. 190), asymmetric response criteria of neuronal circuits shaped by ecological constraints (Flach et al., 2004, p. 88), hitting the head bias (Gray & Regan, 2006), or bias to minimize danger (Schiff & Oldak, 1990).

While TTC estimates are needed in various situations, they are most critical in the case of an impending collision with the observer. If safety strategies play a role in TTC estimation, they are most probably detectable in such situations. Observers overestimate the trajectory's angle of passing objects (Harris & Dean, Philip J. A., 2003; Welchman, Tuck, & Harris, 2004), which may be the result of a contrast effect that aims to quickly and reliably detect objects on a collision course. A quick decision, whether an approaching object is on a collision course or not is the prerequisite for a safety strategy to adapt the organisms perceptions and reactions in the case of an impending collision. Indeed, observers estimate the TTC of objects that will hit them shorter than that of objects that will miss them (Gray & Regan, 2006).

There are more hints that safety strategies are at work in head-on-TTC estimation. That the size of an object influences TTC estimations is known from several studies. For example, drivers' TTC judgments seem to be affected by the usual size of pedestrians. Underestimating the size of children, they overestimate TTC with children, which can result in dangerous situations (Stewart et al., 1993). Observers generally judge TTC of larger objects shorter than that of smaller objects, even if tau gives contrary information (DeLucia, 1991; DeLucia & Warren, 1994). This robust "size-arrival-effect" also surfaces with textured objects (DeLucia, 2004b; Smith, Flach, Dittman, & Stanard, 2001) and with

photorealistic animations (DeLucia, 1991). The size-arrival-effect does also surface in a collision avoidance task in which observers had to virtually approach and "jump" over obstacles of varying size as late as possible. They jumped later when the objects were smaller, even though the necessary jumping height was the same (DeLucia & Meyer, 1999; DeLucia & Warren, 1994). However, if the relative size of real objects is known, the relative size of their simulated equivalents does not have as much of an influence (DeLucia, 2005), probably because previous knowledge of an object's size or form can be included in TTC estimates (López-Moliner, Brenner, & Smeets, 2007; López-Moliner, Field, & Wann, 2007). Since the size of an object can, in principle, be a relatively reliable predictor of its potential to inflict injury, this bias in the processing of an optical variable could reflect a visual safety strategy of its own.

All this said, the question remains, whether there are safety strategies at work in TTC estimation that are *not* just the result of some simple heuristic based on optical variables like a bigger visual angle or the symmetrical radial magnification of a looming stimulus, that signals head-on approaches in contrast to miss-trajectories.

The most obvious question to turn to, in order to answer this general question, was whether there would be a difference between threatening and non-threatening objects approaching on a collision course. Half a century ago, Schiff (1965) tested the reaction of several species, including humans, to different looming stimuli. He used simple shapes like circles, rectangles, or stars and found the same avoidance responses to his stimuli regardless of their shape. Such simple, geometrical shapes probably do not differ enough in terms of perceived threat, or the avoidance response was too crude a measure to detect any additional safety strategy (the avoidance response to looming stimuli itself being a safety strategy of the organism to prevent collisions). To answer the question about the effect of threat, one would have to involve more obvious emotional stimuli.

7.3 The role of emotion

In the tradition of evolutionary psychology and embodied perception and cognition (e.g. Kaschak & Maner, 2009; Proffitt, 2006), I think of emotion and attention – as well as of perception and the nervous system as a whole – as evolved means to aid an organism's survival by guiding its actions, which is guiding its movements. There, in the guidance of movement as the very purpose of a nervous system, is

also a link back to Gibson's ecological approach to visual perception (Gibson, 1979). Emotions can be thought of as effective mechanisms added to such motion-guiding nervous systems, enabling them to modify their responses depending on the situation at hand and thus enabling them to quickly switch to the evolutionary most promising perceptual strategy.

Emotions can not only alter the perception of something as immaterial and elusive as time (Lake, LaBar, & Meck, 2016; Zhang, Liu, Wang, Chen, & Luo, 2014), they can also have an effect on visual perception. For example, by altering attentional processes like visual search (Öhman, Flykt, & Esteves, 2001; Öhman, Lundqvist, & Esteves, 2001), or by directly influencing low-level visual processes like contrast sensitivity (Phelps, Ling, & Carrasco, 2006).

A prerequisite for an emotional trigger of perceptual safety strategies would be a very fast detection and categorization of threatening stimuli. Indeed, object recognition, at least for specific evolutionary relevant objects, is pretty quick. Biological motion dot patterns can be perceived as a moving human body in as short a time as 100 ms (Johansson, 1976). A fear-related picture can elicit a physiological reaction after only 30 ms presentation time – without conscious recognition. Öhman and Soares (1994) have demonstrated this by presenting snake pictures to snake-fearful observers measuring skin conductance responses (SCRs). The same short presentation time prior to a masking stimulus was also sufficient to elicit a conditioned SCR to evolutionary fear-relevant stimuli like snakes, spiders and angry faces in non-fearful observers (Ohman & Soares, 1993; Öhman & Soares, 1994). A possible neuronal basis of such fast detection of snakes has been found by van Le et al. (2013).

Such fast processing of evolutionary threatening stimuli makes the physiological reactions underlying the emotion of fear a suitable candidate to trigger a safety strategy in TTC estimation.

7.4   Overview of the experiments

In Part I of this study, I examine the direct influence of affective stimulus content on TTC estimation. Three topics make up this section:

1. The effect of threatening stimuli[1]

2. The influence of task and threat domain[2]

3. Disentangling arousal, valence and fear[3]

In Part II, I report experiments dealing with another kind of threatening situation, namely the case of impaired visual conditions. Situations in which one cannot see as clearly as usual may also induce a feeling of insecurity and thus may indirectly trigger a safety strategy.

---

[1] published as Brendel, E., DeLucia, P. R., Hecht, H., Stacy, R., & Larsen, J. (2012). Threatening pictures induce shortened time-to-contact estimates. *Attention, Perception, & Psychophysics*, *74*(5), 979–987. https://doi.org/10.3758/s13414-012-0285-0

[2] Published as DeLucia, P. R., Brendel, E., Hecht, H., Stacy, R. L., & Larsen, J. T. (2014). Threatening scenes but not threatening faces shorten time-to-contact estimates. *Attention, Perception, & Psychophysics.* Advance online publication. https://doi.org/10.3758/s13414-014-0681-8.

I contributed in designing the experiments, in discussing data analyses and results, and in writing and revising the introduction, discussions and conclusion.

[3] Published as Brendel, E., Hecht, H., DeLucia, P. R., & Gamer, M. (2014). Emotional effects on time-to-contact judgments: Arousal, threat, and fear of spiders modulate the effect of pictorial content. *Experimental Brain Research.* Advance online publication. https://doi.org/10.1007/s00221-014-3930-0

8 PART I: SAFETY STRATEGIES AND AFFECTIVE CONTENT

8.1 The effect of threatening stimuli[4]

8.1.1 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. 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.

8.1.2 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). We examined the notion that higher-level cognitive factors, represented by affective value of approaching objects, could affect judgments of TTC. Previous studies demonstrated effects of cognitive processes on TTC judgments and demonstrated the effect of affective content on perceptual and cognitive processes, but studies have not examined the effect of affective content on TTC judgments.

8.1.2.1 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). David Lee's (1976) tau-

---

theory assumes that the visual system accomplishes this timing accuracy with a tau-processor which 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, 1997), 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, 2004a, 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 manoeuvre closer to the time of collision and thus making it harder for a predator to counter-react (Xiao & Frost, 2009).

More generally, previous studies 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 et al., 2001), spatial information processing (Crawford & Cacioppo, 2002), memory (Bradley, Greenwald, Petry, & Lang, 1992), and even low-level contrast sensitivity (Phelps et al., 2006).

In light of these findings we expected to find an effect of affective content on TTC judgments. Previous studies have not measured potential affective modulation of TTC estimation.

8.1.2.2 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 TTC of objects that will hit them shorter than that of objects that will miss them (Gray & Regan, 2006).

The question we pose now is whether there is a similar difference between threatening and non-threatening objects that approach on a collision course. After all, we react differently if something soft and harmless is thrown at us compared to something hard, sharp or pointy. Simple shapes like 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 behavioral measures may have been too gross to find any such differences.

The superior colliculus seems to play an important role when deciding if 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 compared to receding or randomly moving stimuli (Billington et al., 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.

8.1.3   Experiments 1 and 2: Threatening versus neutral picture content

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 shorter for threatening stimuli than 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.

8.1.3.1   Method

Nineteen people (mostly students at the University of Mainz), participated in Experiment 1 for course credit or payment (8 men, 11 women; aged 18-47 years, $M = 23.4$; $SD = 6.85$); twenty others participated

in Experiment 2 (8 men, 12 women; aged 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 labelled 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 labelled with intermediate to low arousal ratings and intermediate to high valence and dominance ratings in the catalogue.[5] 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 reassembled in a randomized order to separate the effect of emotional content from low-level image features

Displays were presented in stereo on a 2.60 x 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 & Boss, 1983) TTC estimates were calculated as the time from the pictures' disappearance to the participant's button press. To discourage participants from basing their judgments on 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 1000 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 x 2 presentation durations x 2 widths x 2 velocities x 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

---

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

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.

8.1.3.2   Results

TTC estimates are plotted as a function of actual TTC in Figure 1 (original IAPS) and Figure 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.
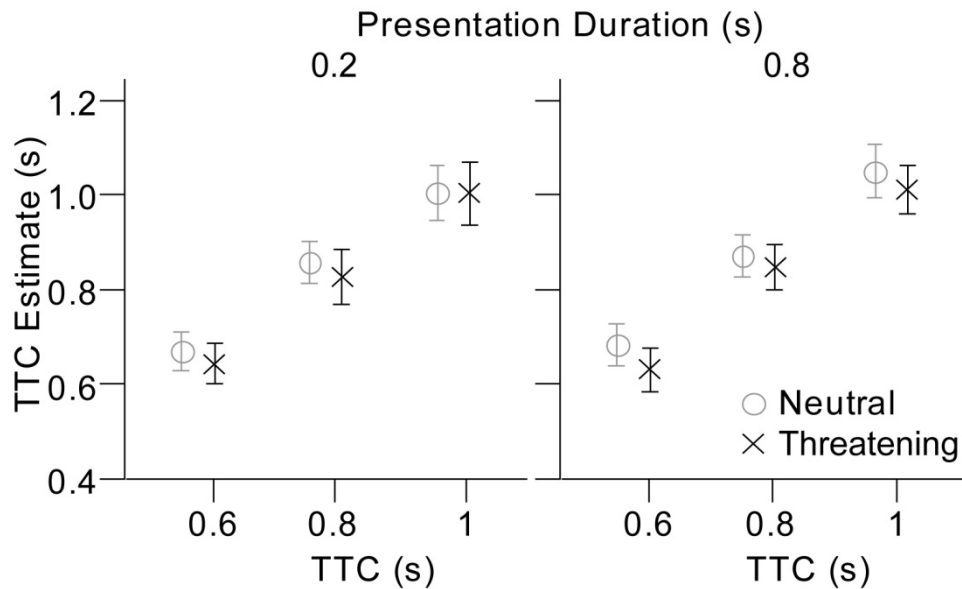
Figure 1. Average TTC estimates as a function of the actual three TTC values (collapsed over velocity and picture

width) for threatening and neutral pictures presented for 200 ms and 800 ms in Experiment 1 (original IAPS). Error

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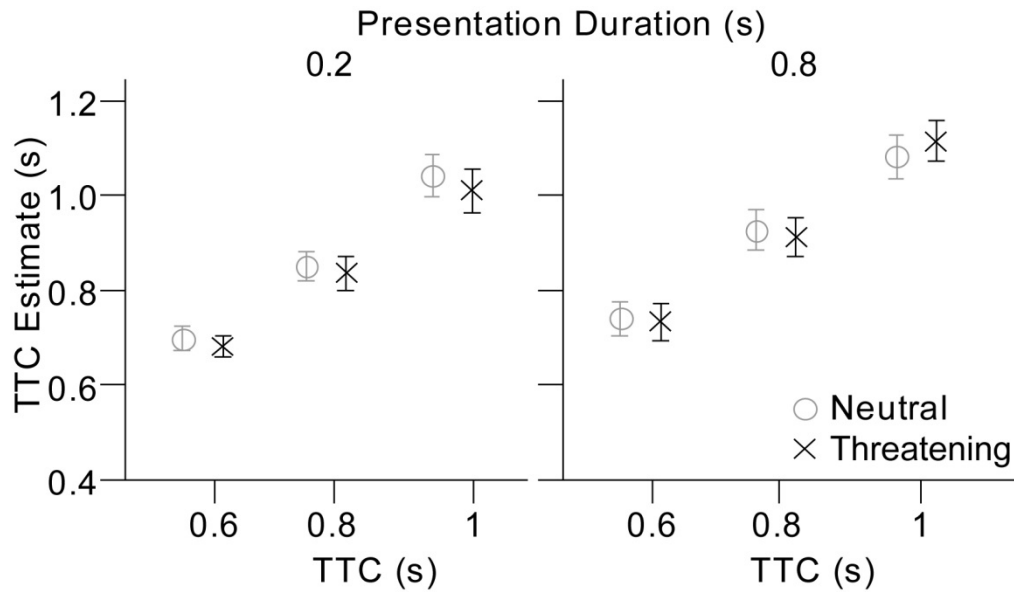
Figure 2. Average TTC estimates as a function of the three actual TTC values (collapsed over velocity and picture width) for threatening and neutral pictures presented for 200 ms and 800 ms in Experiment 2 (scrambled IAPS). Error bars represent standard error of the mean.

Slower velocity and larger picture width each led to shorter TTC estimates in both experiments [original pictures, width: $F(1,18) = 14.3$, $p = .001$, $\eta_p2 = .443$; original pictures, velocity: $F(1,18) = 76.1$, $p < .001$, $\eta_p2 = .809$; scrambled pictures, width: $F(1,18) = 12.9$, $p = .002$, $\eta_p2 = .404$; scrambled pictures, velocity: $F(1,18) = 77.8$, $p < .001$, $\eta_p2 = .804$]. Such effects of velocity and object size are consistent with previous TTC studies (e.g., Caird & Hancock, 1994; DeLucia, 1991; Smith et al., 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, due to the greater starting distance.

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 same as in the full analyses mentioned above. A comparison of these collapsed TTC estimation errors from Experiment 1 and 2 is shown in Figure 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, $F(1,19) = 4.259$, $p = .053$, $\eta_p^2 = .183$.
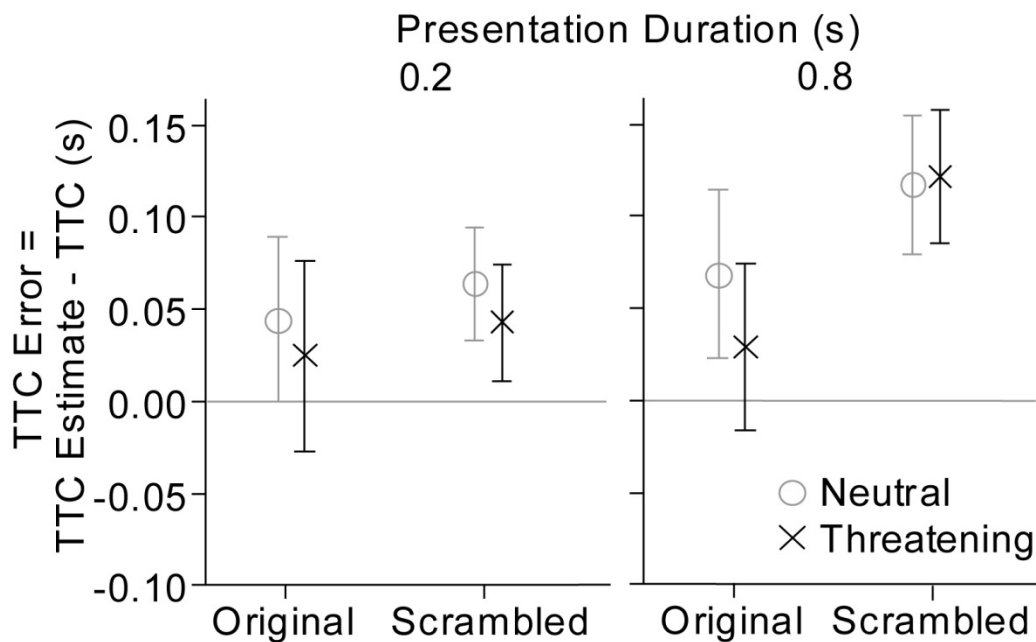
Figure 3. Average TTC estimation errors (collapsed over actual TTC, velocity, and picture width) for threatening and neutral pictures presented for 200 ms and 800 ms combined for Experiment 1 (original IAPS) and Experiment 2 (scrambled IAPS). Error bars represent standard error of the mean.

Combined Analysis of Experiment 1 and 2. We compared the results of Experiment 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 neutral ones, but only with original pictures at the longer presentation duration (see Table 1).

Table 1. T-test results comparing TTC estimation errors of neutral and threatening pictures from Experiment 1 and 2

Experiment	Presentation Duration (ms)	TTC Estimate Difference Threatening - Neutral (ms)		Paired t	df	p
		M	SD			
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

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 $F < 2.3$; all $p > .1$).

SAMs ratings (see Table 2) were analysed 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 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, $F(1,37) = 6.557$, $p = .015$, $\eta_p^2 = .151$).

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)

Picture Type	Arousal Rating 1 = calm 9 = excited		Valence Rating 1 = unhappy 9 = happy		Dominance Rating 1 = dominated 9 = dominant	
	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

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; $t(19) = .299$, $p = .768$).

8.1.3.3   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.

8.1.4   Experiment 3: Facial expressions

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 based on Öhman, Lundqvist and Esteves'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.

8.1.4.1   Method

Twenty people (mostly students at the University of Mainz), participated in Experiment 3 for course credit or payment (4 men, 16 women; aged 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; model # 20 and 23, open-mouthed version)[6] in addition to an "empty" face with all facial features erased.

8.1.4.2   Results

Again performance was very consistent, reflecting true TTC quite well, and showing just small differences between the emotional facial expressions (see Figure 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 Figure 5. They were analyzed with a 2 (presentation duration) x 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, $F(1,19) = 5.619$, $p = .028$, $\eta_p2 = .228$. The interaction between emotion and presentation time was not significant, $F(3,57) = .353$, $p = .787$, $\eta_p2 = .018$. 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 Figure 5).

---

[6] The facial stimuli were obtained through the Research Network on Early Experiences and Brain Development website, http://www.macbrain.org/resources.htm.
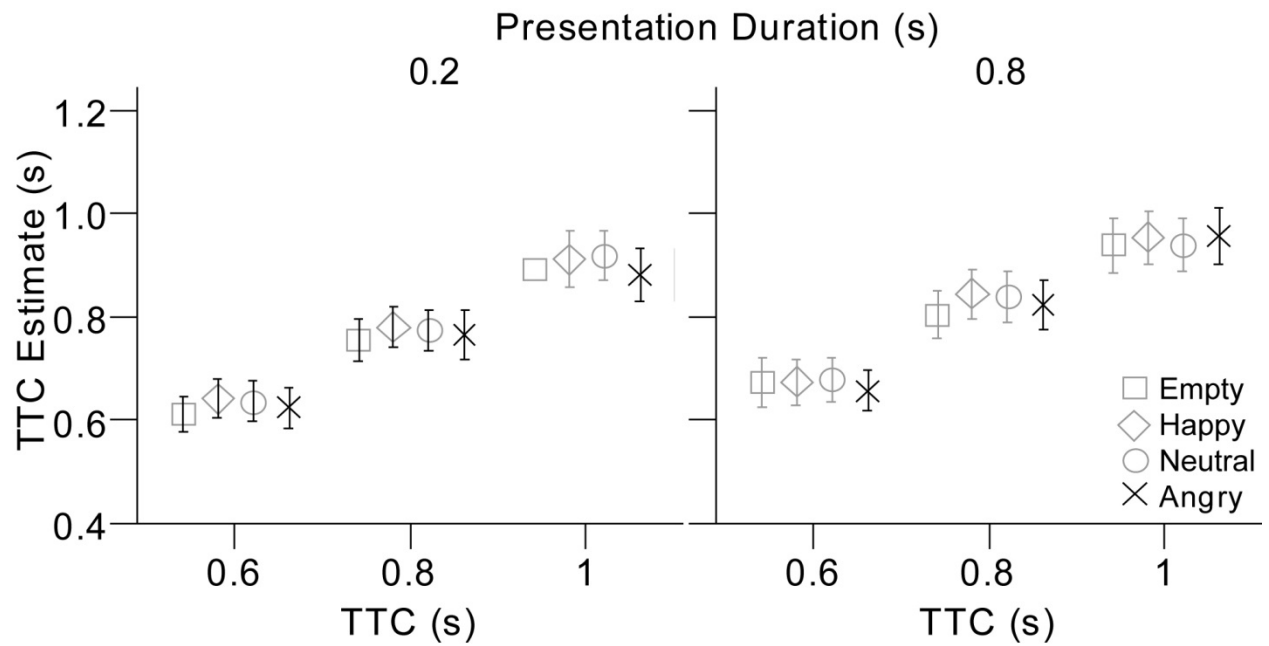
Figure 4. Mean TTC estimates as a function of the actual TTC values (collapsed over velocity and picture width) for pictures of facial expressions presented for 200 ms and 800 ms in Experiment 3. Error bars represent standard error of the mean.
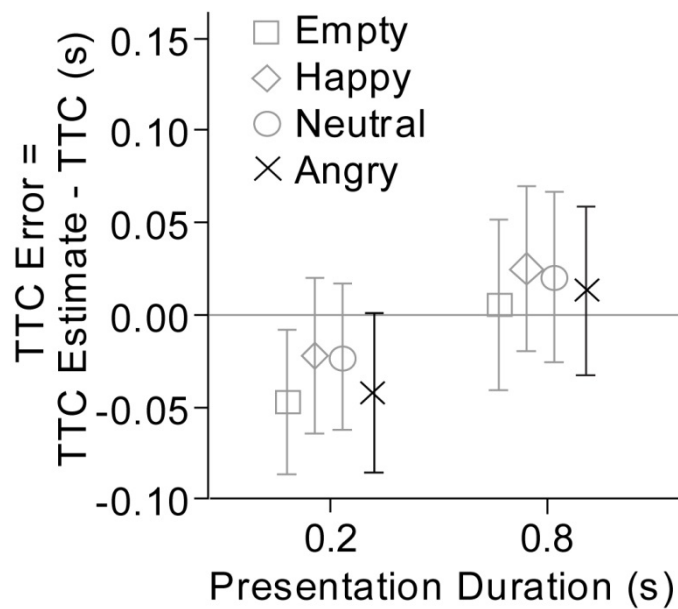
Figure 5. Mean TTC estimation errors (collapsed over actual TTC, velocity, and picture width) for pictures of facial expressions presented for 200 ms and 800 ms in Experiment 3. Error bars represent standard error of the mean.

Table 3.   T-test results comparing TTC estimation errors of facial expressions from Experiment 3

Pair of Facial Expressions	TTC Estimate Difference (ms)		*Paired t*	*df*	*p*
	Mean	SD			
Empty - Friendly	-22	30	-3.280	19	0.004*
Empty - Angry	-6	38	-0.740	19	0.468
Empty - Neutral	-20	31	-2.798	19	0.011
Friendly - Angry	16	28	2.556	19	0.019
Friendly - Neutral	3	30	0.394	19	0.698
Angry - Neutral	-13	38	-1.566	19	0.134

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

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) x 2 (emotion) repeated-measures ANOVA. Based on 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, $F(1,19) = 4.81$, $p = .041$, $\eta_p2 = .202$, while the effect of presentation duration was still significant, $F(1,19) = 6.32$, $p = .021$, $\eta_p2 = .250$, and the interaction of emotion and presentation duration was not, $F(1,19) = 1.17$, $p = .293$, $\eta_p2 = .058$.

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-levelled 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", $F(1,37) = 9.41$, $p = .004$, $\eta_p2 = .203$, and significantly later at the longer presentation duration, $F(1,37) = 4.94$, $p = .032$, $\eta_p2 = .118$.

There was no significant main effect of the factor experiment and no significant interaction (all $F < 2.6$; all $p > .1$). 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 the angry faces, $t(37) = 2.553$, $p = .015$.

8.1.4.3 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, compared to 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.

8.1.5 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 SAMs ratings. It remains to be tested if 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 interpretations consistent with our data. Firstly, the emotion-guided process should be very fast and independent of more time-demanding cognitive evaluation. Secondly, angry faces could just not provide the same level of arousal as pictures of attacks, while both are being processed in the same fashion.

8.1.5.1 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 compared with 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 Figure 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; 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 non-threatening image features and automatically allocate attention without conscious perception of the threat (Lin, Murray, & 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, as 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 may 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 study and requires further tests. In conclusion, TTC estimation seems to be influenced both by fast, bottom-up affective processes as well as slow, top-down cognitive processes.

8.1.5.2 Just an effect on attention and reaction time?

Shorter TTC estimates of threatening pictures could result from faster reaction times in the presence of more arousing stimuli. Emotion affects attentional processes such as focused attention and visual search (Öhman, Lundqvist et al., 2001), and low-level visual processes like contrast sensitivity (Phelps et al., 2006). Even when labels like "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 to 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 study, however, TTC values always exceeded the necessary reaction times; participants always had at least 600 ms of motion extrapolation after the image disappeared from view whereas the average reaction time to a visual stimulus is below 250 ms (Galton, 1890). In addition, the pattern of results from Experiments 1 and 2 speaks against reaction time modulation as an explanation: The shortening of TTC estimates for attack pictures was more pronounced at the longer presentation duration, when the influence of a reaction time advantage of threatening pictures should have been smaller.

8.1.5.3 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 et al., 2011), and angry faces (Gil & Droit-Volet, 2011) compared to neutral ones. In the latter,

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 compared to 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). The authors of this study attributed this high arousal effect to a sub-cortical pathway 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, that 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 due to altered time perception rather than a cognitive processing of the stimulus content.

8.1.6   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.

8.2 The influence of task and threat domain[7]

8.2.1 Abstract

We previously reported that time-to-contact (TTC) judgments of threatening scene pictures (e.g., frontal attacks) resulted in shortened estimations and were mediated by cognitive processes, and that judgments of threatening (e.g., angry) face pictures resulted in a smaller effect and did not seem cognitively mediated. In the current study, the effects of threatening scenes and faces were compared in two different tasks. An effect of threatening scene pictures occurred in a prediction-motion task, which putatively requires cognitive motion extrapolation, but not in a relative TTC judgment task which was designed to be less reliant on cognitive processes. An effect of threatening face pictures did not occur in either task. We propose that an object's explicit potential of threat per se and not only emotional valence underlies the effect of threatening scenes on TTC judgments and that such an effect occurs only when the task allows sufficient cognitive processing. Results are consistent with distinctions between predator and social fear systems and differential underlying physiological mechanisms. Not all threatening information elicits the same responses, and whether an effect occurs at all may depend on the task and the degree to which the task involves cognitive processes.

8.2.2 Introduction

Estimating the time-to-contact (TTC) of approaching objects is a crucial perceptual ability of any mobile animal. In principle, such estimation could rely on simple optical characteristics that are defined by looming visual stimuli and that can provide an exact measure of TTC without the need to estimate velocities and distances (Lee, 1976). Such a simple, optical computation of TTC does not seem to be realized in humans. Many factors influence TTC estimation, including non-optical factors such as limits in cognitive processing (Baurès et al., 2010; DeLucia & Novak, 1997; Novak, 1997). Recent studies show that TTC estimation also is affected by emotion: Threatening pictures of frontal attacks (Brendel et al.,

---

2012) or of feared animals (Vagnoni, Lourenco, & Longo, 2012) shortened TTC estimates in a prediction-motion (PM) paradigm. Pictures of angry faces had a similar albeit smaller effect (Brendel et al., 2012). Interestingly, the effect of threatening pictures occurred with relatively longer presentations and the effect of facial expression did not take as long to surface. This suggests that the recognition of frontal attacks was more cognitively mediated and the effect of facial expressions was more direct. However, the distinction between the effects of threatening pictures and emotional expressions on TTC estimation was mostly speculative and still needs to be resolved (Brendel et al., 2012).

There are good reasons to believe that faces and attack-scenes or feared animals should have different effects on TTC estimation. As stated eloquently by Arne Öhman, who distinguished between predator fear and social fear:

"It is only in the encounter with the beast that one tries hard to avoid the real threat, the animal. In the social conflict what one primarily seeks to avoid is being humiliated, and this is even more important than avoiding getting oneself killed." (Öhman, 1986, p. 124)

Indeed, there seem to be distinct neural fear circuits that process fear of predators, fear of pain, and fear of aggressive conspecifics (social fear). These distinct fear circuits seem to process information independently and in parallel, and they are evolutionarily conserved across vertebrates (Gross & Canteras, 2012). Thus, although pictures of angry faces are effective stimuli for human conditioning (Lang, Davis, & Öhman, 2000), they likely trigger a different mechanism than other threatening stimuli.

The predator fear system and the social fear system evoke different brain patterns and physiological reactions: A recent meta-analysis of 157 functional magnetic resonance imaging (fMRI) studies examining emotional face processing and emotional scene processing revealed great overlapping activity patterns, but also several differences, among them greater amygdala activation in response to emotional faces as compared to emotional scenes (Sabatinelli et al., 2011). The authors attributed this difference to the amygdala's role in facial recognition and identification. Analyzing facial features is probably the most important aspect of emotional face processing. Facial features are used to decode the social signal conveyed through the facial expression and to predict an aggressor's intentions specifically when conveyed by a threatening or angry face. Consistent with this notion, the amygdala is no longer thought to be activated by the experience of fear but rather by the perception of fear (Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Wager et al., 2008) or, more generally, by the perception of

"motivationally salient events that require attention and learning" (Wilson-Mendenhall, Barrett, Simmons, & Barsalou, 2011).

Moreover, various psychophysiological responses (heart rate, electrodermal activity, startle reflex) are modulated differently by faces and scenes in spite of comparable valence and arousal ratings (Alpers, Adolph, & Pauli, 2011). For example, psychophysiological measures (electrodermal reactivity and startle reflex potentiation), and event-related brain potentials (the centro-parietal late positive potential), are modulated much less by emotional face expressions than emotional scenes (Wangelin, Bradley, Kastner, & Lang, 2012). Differences between the social fear system and the predator fear system make sense because the social fear system has to be flexible and cognitively controllable to assess the actual threat in the given situation, whereas the predator fear system has evolved to quickly prepare the organism for a survival-ensuring fight or flight reaction (Öhman, 1986). It has been proposed that the predator fear system responds in situations of grave physical threat or potential of death (Gross & Canteras, 2012). Thus, it is reasonable to expect response differences between pictures of scenes showing an overt attack and pictures of angry faces for which the threat is ambiguous.

In principle, any solid object approaching on a direct collision course poses a direct threat of physical harm to the observer. The semantic content of the approaching virtual pictures used in our experiments, however, can be classified into a predator threat context (presumed to activate the predator fear system) and a social threat context (presumed to activate the social fear system). The distinction between both kinds of stimuli is not as clear-cut as one would wish for this kind of experiment: An approaching predator may be seen as a welcome opportunity to impress con-specifics, and an aggressive human can be thought to activate the predator fear system instead of the social fear system depending on the context, for example whether there are spectators to acknowledge the outcome of a fight. However, whereas the social threat posed by an angry face may be ambiguous, the physical threat posed by an approaching knife-wielding attacker is obvious and may represent even more of a predator threat than does an animal predator – even more so if the facial features of the attacker are occluded by a black face mask. Therefore, we used both a masked attacker with a knife and a biting snake as scene pictures depicting physical threat, and compared them to neutral and friendly scene pictures. We used angry facial expressions without any contextual information as face pictures depicting social threat, and compared them to neutral and friendly face expressions.

This classification of stimuli into threatening scenes and threatening faces and respective links to the predator and social fear systems is consistent with methods used in prior studies investigating emotional reactions to different stimuli. These include comparisons of emotional scene processing and emotional face processing based on a meta-analysis of fMRI studies that reported studying "scenes" and "faces" Sabatinelli et al. (2011), and comparisons based on the labels and the source of the pictures (i.e., databases of scene and face images; Alpers et al., 2011). For example, Alpers et al. reported that physiological responses to emotional scenes (e.g., attacking animals, human attack, from the International Affective Picture System; Lang et al., 2005) differed from responses to emotional faces (e.g., angry, neutral faces, from the NimStim set of images; Tottenham et al., 2009). Our stimuli also are consistent with the idea that the predator fear system is activated when there is potential for grave physical harm or death and the social fear system is activated by aggressive conspecific cues (Gross & Canteras, 2012).

In short, it is important to determine whether the threat portrayed in scenes and the threat portrayed by emotional facial expressions affect TTC estimation, which is critical for evading an approaching physical threat but not necessarily for averting a social threat. Öhman, Lundqvist et al. (2001) reported that visual search for a discrepant face in a matrix of distracting faces was faster and more accurate when the discrepant face was angry compared with friendly. At first glance, it is reasonable to expect that this "threat advantage" would occur in TTC judgments (as suggested by our initial results; Brendel et al., 2012). However, if the social fear system and the predator fear system activate different mechanisms (e.g., cognitive vs direct), the results may depend on experimental parameters, particularly the nature of task.

We report five experiments aimed to differentiate the effects of threatening scenes (human, snake posing an attack) and threatening faces (angry facial expressions) on TTC estimation of approaching objects in two different tasks considered to differ in their reliance on cognitive processes. In Experiments 4 (face pictures) and 5 (scene pictures), we tested whether faces constitute a special class of stimuli, using the prediction-motion task (absolute TTC judgments) described by Brendel et al. (2012). In Experiment 6, we examined whether the abstract facial stimuli used in visual search tasks (Öhman, Lundqvist et al., 2001) affected TTC estimation. In Experiments 7 and 8, participants made relative TTC judgments in a two-alternative forced choice paradigm with the same stimuli as Experiments 4 and 5. We will see that

there is an effect of threatening scenes but not threatening faces and that this effect occurs only when the task involves cognitive processing.

8.2.3 Experiments 4 and 5: Threatening scenes and faces in PM task

The purpose of Experiments 4 and 5 was to compare the effects of threatening faces (i.e., angry face) and threatening scenes (i.e., frontal attack) on TTC judgments in a PM task. Shortened TTC judgments for threatening faces and scenes in both categories would extend Brendel et al.'s (2012) results and suggest similar mechanisms for effects of threat in both types of stimuli.

8.2.3.1 Method

Participants. Thirty-two students from Texas Tech University participated for course credit in Experiment 4 (16 men, 16 women; aged 18-53, $M = 20.19$; $SD = 6.20$). Thirty-two different students participated in Experiment 5 (16 men, 16 women; aged 18-22, $M = 18.81$; $SD = 1.12$). All reported having normal or corrected visual acuity. Sample size was motivated by the relatively high variability of PM judgments compared with relative TTC judgments in Experiments 7 and 8 (see Tresilian, 1995).

Displays. Displays were presented on a 43-cm monitor at 25 frames/s and were viewed with a chin rest from 45.72 cm. We simulated an object that approached the participant directly for 3 s and disappeared from view. To create a variety of trials, the initial distance between the approaching object and the viewpoint was relatively near or far, and the actual TTC at the time of the object's disappearance was .75 s, 1.5 s, or 3 s.

In Experiment 4 (threatening faces), the object depicted a digitized photograph of a real face. The set of photographs consisted of angry, happy, and neutral facial stimuli from the NimStim Set of Facial Expressions that were used by Brendel et al. (2012). Two different models were included (Tottenham et al., 2009; model # 20 and 23, open-mouthed version) in addition to an "empty" face with all facial features erased.

In Experiment 5 (threatening scenes), the object depicted pictures from the International Affective Picture System (IAPS, Lang et al., 2005) rather than facial expressions. Pictures were selected from the sample used by Brendel et al. (2012). A masked attacker with a knife and a biting snake represented threatening stimuli. A lamp and a clock represented neutral stimuli. A boy and a baby represented friendly stimuli. The IAPS numbers of the pictures used were 1120, 2070, 2650, 6510, 7175,

and 7190. In addition, empty colored squares were included as a control stimulus without affective content.

In both experiments, the orientation of the approaching object was upright or inverted. Facial recognition and discrimination is degraded when faces are inverted, suggesting that faces are processed holistically rather than analytically (Pallett & MacLeod, 2011). However, studies indicate that the processes involved in facial recognition are different from the processes involved in the identification of emotional expressions, and that the processing of facial expressions of emotion is not degraded when inversion is used to disrupt holistic processing (Lipp, Price, & Tellegen, 2009; Öhman, Lundqvist et al., 2001). In Öhman et al.'s (2001) visual search study, the threat advantage occurred with inverted faces. We included this orientation manipulation to ascertain whether we would obtain the same pattern of results and thus presumably activate the same type of processing.

Procedure. Participants were instructed to press a mouse button when they thought that the object would hit them had the simulation of the object's motion continued after it disappeared. Participants viewed each of 96 unique trials three times in randomized orders.

8.2.3.2 Results

Results of Experiments 4 and 5 were analyzed separately with 2 (orientation) x 4 (affective content) repeated-measures ANOVAs and are shown in Figures 6 and 7. In Experiment 4 (threatening faces), the effect of emotional expression on mean TTC estimates was not significant, $F (3, 93) = 2.15$, $p = .099$, $\eta_p^2 = .06$. Mean TTC estimates were greater for the inverted faces ($M = 2.94$ s) compared with the upright faces ($M = 2.88$ s), $F(1, 31) = 9.83$, $p = .0037$, $\eta_p^2 = .24$.
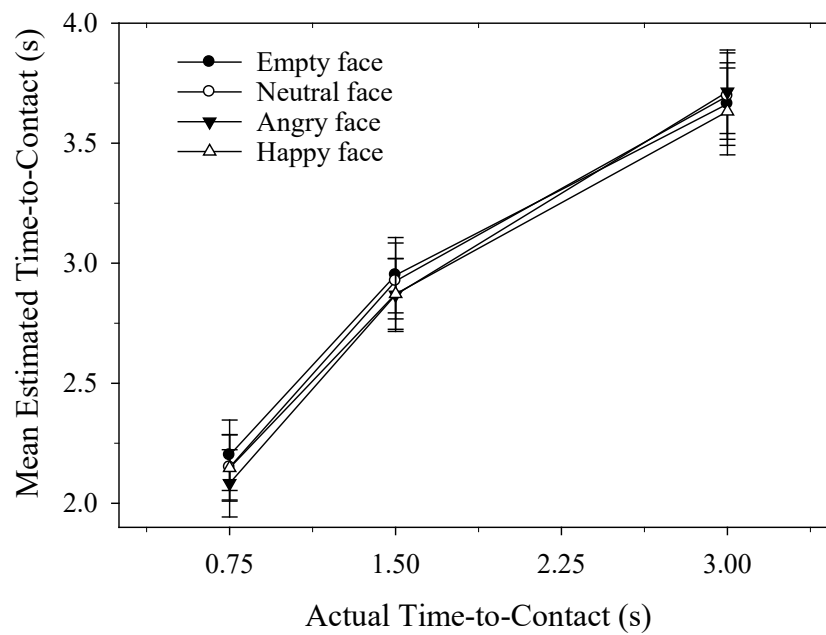
Figure 6. Experiment 4. Mean estimated time-to-contact as a function of actual time-to-contact for neutral, angry, happy, and empty faces (averaged over final distance and orientation). Error bars represent standard errors of the means.

In contrast, results of Experiment 5 (threatening scenes) indicated a main effect of affective content of the scene pictures, $F(3, 93) = 12.69$, $p = .0001$, $\eta_p^2 = .29$, but not of orientation or their interaction ($Fs < 1.33$, $ps > .27$). Results of Tukey's HSD tests indicated that the mean TTC estimate was shorter for the threatening pictures (attacker, snake) than neutral (lamp, clock) and friendly (baby, boy) pictures. The difference between threatening pictures and empty squares was not significant.
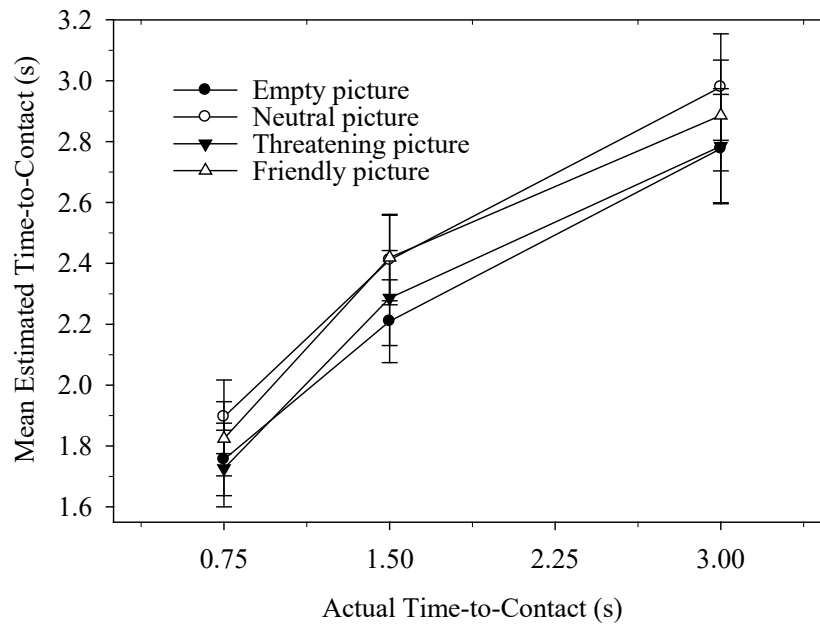
Figure 7. Experiment 5. Mean estimated time-to-contact as a function of actual time-to-contact for neutral, threatening and friendly pictures (averaged over final distance and orientation). Error bars represent standard errors of the means.

The results of Experiments 4 and 5 were directly compared with a 2 (orientation) x 2 (experiment) x 4 (affective content) mixed ANOVA. Only significant effects of experiment or interactions with experiment are reported. There was a main effect of experiment, $F(1, 62) = 7.95$, $p = .0064$, $\eta_p^2 = .11$, and an interaction between experiment and affective content, $F(3, 186) = 9.64$, $p = .0001$, $\eta_p^2 = .13$. Overall, mean TTC estimates were shorter for scene pictures ($M = 2.33$ s), compared with face pictures ($M = 2.91$ s). A 2 (orientation) x 2 (experiment) ANOVA conducted at each level of affective content indicated that mean TTC estimates were greater in Experiment 4 (face pictures) than 5 (scene pictures) at all levels of affect, Fs > 5.6, ps < .02. Means are shown in Figure 8. Analyses of effects of affective content for each experiment separately were reported above for results of Experiments 4 and 5.
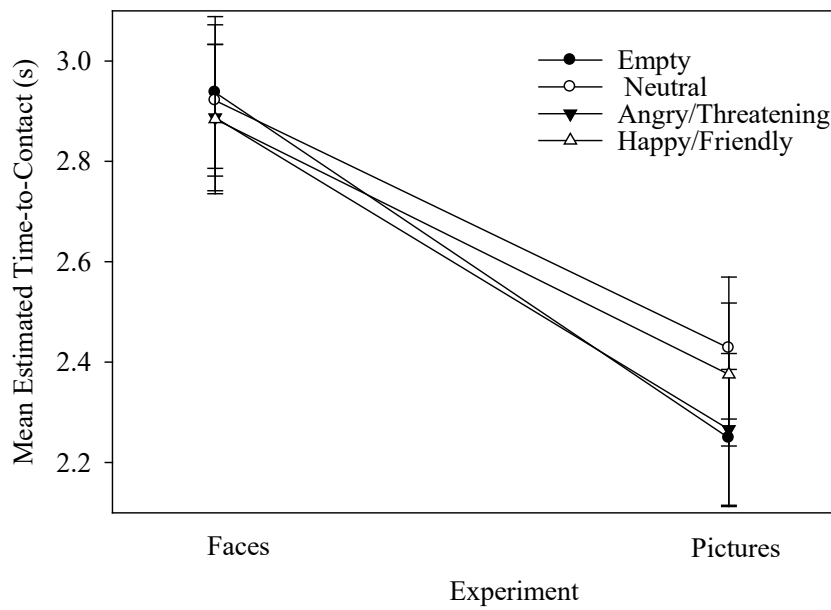
Figure 8. Experiments 4 and 5. Mean estimated time-to-contact in Experiment 4 (face pictures) and 5 (scene pictures) for empty, neutral, angry/threatening and happy/friendly pictures. Error bars represent standard errors of the means.

8.2.3.3 Discussion

Threatening scene pictures (attacks) were judged to arrive earlier than neutral and friendly pictures in a PM task. This finding replicates the effect of threatening scene pictures reported by Brendel et al. (2012). However, TTC judgments were not affected by threatening faces (angry face expressions). Taken together, the results of Experiments 4 and 5 support our previous observation that the effect of facial expressions is weaker than that of threatening scene pictures (Brendel et al., 2012). We discuss the differences between facial and other pictorial emotional stimuli in our general discussion.

Interestingly, empty pictures (colored squares) were judged to arrive as early as threatening pictures. A similar finding was observed in a related study (Brendel & Hecht, 2013), that is, stimuli without meaningful content were judged to arrive as early as those with threatening content. This may be explained by a general distraction effect of content; that is, pictorial content generally distracts from the task and this distraction leads to longer TTC estimates. Threatening content can diminish this effect and lead to TTC estimates as short as those of pictures without meaningful content (the empty squares). Emotionally neutral or friendly content may allow for more interpretation and may impose less urgency to correctly solve the task and thus lead to the observed overestimation. A similar effect was reported in

time perception (Lambrechts, Mella, Pouthas, & Noulhiane, 2011): In a time reproduction task, participants estimated the 2-s duration of a grey square as shorter than that of a picture with content, regardless of whether the content was neutral or emotional. At longer durations, however, this general content effect on time estimation diminished and an emotional content effect appeared. Specifically, the 4-s duration of an emotional picture was estimated as longer than a neutral picture. It is debatable whether the general content effect putatively observed in our measures of TTC judgments is comparable to the effect reported in time estimation studies. In Experiments 4 and 5, although TTC judgments of threatening and content-free pictures were similar (general content affect), there also were differences between threatening pictures and pictures with neutral content (effect of emotional content). Specifically, TTC judgments of neutral and friendly pictures were overestimated whereas TTC judgments of threatening pictures were overestimated by a smaller magnitude and were comparable to judgments of content-free pictures.

8.2.4 Experiment 6: Abstract face stimuli

The results of Experiments 4 and 5 indicated that threatening scene pictures but not threatening face pictures affected TTC judgments in a PM task. An effect of faces was expected on the basis of Öhman, Lundqvist, and Esteves'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 compared with friendly. In addition, Brendel et al. (2012) found a small effect of emotional facial expressions in their study. One possible explanation of our results is that (digitized photographs of) real faces were used in the present study and in Brendel et al.'s study, whereas Öhman, Lundqvist et al. used abstract faces. Although previous studies have shown that the threat advantage in visual search can occur with real faces (Lipp et al., 2009), an experiment was conducted to determine whether an effect of facial expression on TTC judgments would be obtained with Öhman's abstract face stimuli.

8.2.4.1 Method

Participants. Thirty-two students at Texas Tech University participated for course credit (16 men, 16 women; aged 18-25, $M = 18.75$; $SD = 1.65$). All reported having normal or corrected visual acuity and had not participated in Experiment 4 or 5.

Displays. Displays were presented on a 43-cm monitor at 25 frames/s and were viewed with a chin rest from 45.72 cm. The stimuli are represented in Figure 9; they depicted an abstract face that

approached the participant directly for 3 s and disappeared from view. The emotional expression of the face was threatening, friendly, or neutral, created from Öhman, Lundqvist et al. (2001): Figure 1. An "empty" face without facial features was included. To control for local stimulus features apart from emotional expression, in three additional stimuli the facial features were rearranged (scrambled). As in Experiments 4 and 5, the initial distance between the face and the viewpoint was relatively near or far, actual TTC was .75 s, 1.5 s, or 3 s, and orientation was upright or inverted.
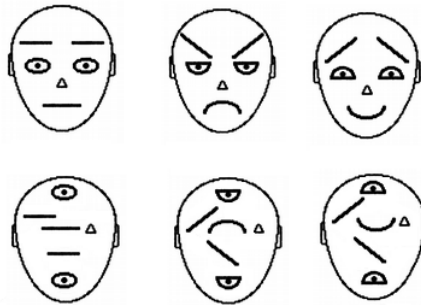
Figure 9. Representations of upright face pictures used in Experiment 6. Left, middle, and right columns depict neutral, threatening, and friendly faces, respectively. Top row: Unscrambled facial features. Copyright © 2001 by the American Psychological Association. Reproduced with permission. The official citation that should be used in referencing this material is Öhman, A., Lundqvist, D., & Esteves, F. (2001). The face in the crowd revisited: A threat advantage with schematic stimuli. *Journal of Personality and Social Psychology, 80*(3), 381–396. Retrieved March 09, 2011, from doi:10.1037/0022-3514.80.3.381. The use of APA information does not imply endorsement by APA. Bottom row. Scrambled facial features.

Procedure. Participants were instructed to press a mouse button when they thought that the object would hit them had the simulation of the object's motion continued after it disappeared. Participants viewed each of 84 unique scenes three times in a randomized order.

8.2.4.2   Results

A 2 (orientation) x 2 (scrambledness) x 3 (emotion) repeated-measures ANOVA was used to analyze TTC estimates. The empty face was omitted because it could not be crossed with scrambledness. Results indicated that main effects of emotional expression and orientation were not significant ($Fs < 2.2$, $ps > .15$). There was an interaction between scrambledness and orientation, $F(1, 31) = 6.04$, $p < .020$, $\eta_p^2 = .16$. A 2 (scrambledness) x 3 (emotion) repeated-measures ANOVA on each level of orientation indicated that mean TTC estimates were greater when pictures were unscrambled than scrambled but only when orientation was inverted, $F(1,31) = 15.47$, $p < .0004$. Such results are again consistent with a general

content effect: When pictures were inverted, the scrambled faces were probably not recognizable and thus were treated like a meaningless pattern (similar to the empty squares Experiment 5). The unscrambled faces, however, were recognizable even when inverted and thus led to longer TTC estimates similar to the neutral scene pictures in Experiment 5. Finally, a separate analysis including empty faces (averaging over the scrambledness variable) indicated that mean TTC estimates for the empty face was greater than for the neutral, threatening, and friendly faces, $F(3, 93) = 5.91$, $p < .002$, $\eta_p^2 = .16$ ($p < .05$ for Tukey's HSD tests).

8.2.4.3   Discussion

Emotional expression did not affect TTC estimates in a PM task even with Öhman, Lundqvist, and Esteves's (2001) facial stimuli. It has been argued that the effect of Öhman's schematic faces could have been driven by low-level features instead of emotional relevance, that is, by a different relationship between the facial surround and the facial features (Mak-Fan, Thompson, & Green, 2011; Purcell & Stewart, 2010). Öhman et al., reported the threat advantage with inverted faces. We included inverted and scrambled schematic faces to control for this possibility in case we found an effect of emotional expression. The absence of an effect of emotional expression on TTC judgments with all of these stimuli suggests that low-level features of schematic faces are effective in visual search tasks but not in TTC estimation tasks.

Generally, not all results from studies using visual search tasks are consistent with an effect of threat. Granted, pictures of snakes or spiders were found faster in picture-arrays of flowers or mushrooms than vice versa (Öhman, Flykt et al., 2001). This effect was even more pronounced when the participants were specifically fearful of those animals (Öhman, Flykt et al., 2001). Further, the effect emerges independently of the threat's phylogenetic origin -- it was also shown for pictures of modern threats like guns and syringes (Blanchette, 2006; Brosch & Sharma, 2005). However, while replicating the threat advantage effect with snakes and spiders, Tipples, Young, Quinlan, Broks, and Ellis (2002) also found faster visual search for harmless animals (e.g. bunnies, puppies, kittens) and fruits, which indicates that the effect may depend not on threat or fear but rather on different features of the stimuli or on different aspects of attentional or emotional reactions.

Critical to our experiments, not all photographic emotional face stimuli seem to be able to affect visual search tasks (Öhman, Juth, & Lundqvist, 2010). Clearly the abstract face drawings we used here

were not sufficient to produce the threat effect on TTC judgments that we observed with the threatening scene pictures in Experiment 5. We considered the possibility that our specific emotional faces were not the most effective ones in eliciting the threat effect, which seems to depend on several features of the stimulus material such as male sex (Becker, Kenrick, Neuberg, Blackwell, & Smith, 2007; Öhman et al., 2010) and familiarity (i.e., small sample size) of the faces (Öhman et al., 2010). In additional experiments, we validated that visual search was faster and more accurate for threatening faces than friendly faces even when the photographic facial stimuli from Experiment 4 were used rather than the abstract faces used in Experiment 6.[8] Thus, the absence of an effect of emotional facial expression on TTC judgments in Experiment 4 was not due to our use of digitized photographs of real faces. The implication is that Öhman's abstract faces and our photographic faces have a threat advantage effect in visual search but not in time-to-contact estimation. In other words, the effects of facial expressions are task-specific. This result is not surprising from an evolutionary point of view: The involvement of the social fear system to improve the detection of an angry face in a crowd seems to be quite useful, whereas the interpretation of social threat cues should be less valuable for the timing of evasive or interceptive actions – which are the most important functions of the perception of TTC.

8.2.5 Experiments 7 and 8: Threatening scenes and faces in relative judgment task

The purpose of Experiments 7 and 8 was to determine whether the differences between the effects of threatening scene and face pictures obtained in Experiments 4 and 5 were specific to the PM task. In Experiments 7 and 8 relative TTC judgments were measured. Two objects approached the observer side-by-side and were occluded before the first object reached the observer's eye plane. Observers had to pick

---

[8] Two experiments (N=20 in each) replicated Öhman et al.'s (2001) visual search task with digitized photographs of upright and inverted faces, respectively, using the neutral, happy and angry faces from Experiment 4. The faces were arranged in 3 x 3 matrices. In half of the matrices, there was one "discrepant" face that was different from the remaining "distractor" faces. The discrepant face depicted an emotional expression of angry, happy, or neutral, and appeared with equal frequency in each of the nine locations of the matrix. The discrepant face was present amidst distractor faces that were either emotional or neutral (e.g., angry discrepant face presented with all happy distractor faces or all neutral distractor faces). In the remaining matrices, all the faces were either angry, happy, or neutral. Whereas Öhman et al (2001) used presentations of only 1 s and 2 s, we added a 3-s duration to match the duration of our approach scenes in Experiment 6. Results replicated Öhman et al.'s primary finding that mean response time was significantly faster [upright: $F(1, 19) = 14.49$, $p = .0012$, $\eta_p^2 = .43$; inverted: $F(1, 19) = 10.06$, $p = .0050$, $\eta_p^2 = .35$], and percentage accuracy was significantly higher [upright:$F(1, 19) = 27.59$, $p = .0001$, $\eta_p^2 = .59$; inverted: $F(1, 19) = 55.14$, $p = .0001$, $\eta_p^2 = .74$] when the discrepant face was angry compared with happy. These findings also occurred with the 3-s presentation duration. As reported by Öhman et al. (2001) the threat advantage also occurred with inverted faces. This speaks for the position that the processing of emotional face expressions, which is not degraded by inversion, is separable from the processing of facial recognition, which is degraded by inversion (Lipp, Price, & Tellegen, 2009; Öhman, Lundqvist, & Esteves, 2001).

the object that would reach them first. This relative TTC task is less reliant on cognitive processes than the PM task used in Experiments 4 and 5, because in the relative TTC task the viewing time of the approaching objects was 1 s rather than 3 s, and the participant's response occurred immediately after the target disappeared (see Tresilian, 1995). By reducing a reliance on cognitive processes, the effect of threatening pictures my not occur in Experiments 7 or 8. Although we did not find an effect of facial expressions on TTC judgments in Experiment 4, we examined the effect of facial expressions in Experiment 7 to determine whether the absence of an effect was specific to the PM task used in Experiment 4.

8.2.5.1 Method

Participants. Twelve new students participated in Experiment 7 (6 men, 6 women; aged 17-20, $M =$ 18.75; $SD = .87$). Twelve different students participated in Experiment 8 (6 men, 6 women; aged 18-22, $M = 18.67$; $SD = 1.15$). All reported having normal or corrected visual acuity and had not participated in Experiments 4, 5, or 6.

Displays. Displays simulated two objects, positioned side by side, that approached the viewpoint on a non-collision path for 1 s and disappeared from view. In Experiment 7, the angry, happy, and neutral face pictures from Experiment 4 were used but only one model was included (model # 23, open-mouthed version), and the empty face was excluded. In Experiment 8, the attacker, baby, and lamp scene pictures from Experiment 5 were used. In both experiments, the stimuli were oriented upright or inverted, and the pairings of the pictures were manipulated. In Experiment 7 the pairings were neutral and happy, neutral and angry, happy and angry. In Experiment 8, the pairings were lamp and baby, lamp and attacker, baby and attacker. On one-third of the trials, both objects arrived simultaneously (ties). To eliminate relative optical size as a cue for relative TTC judgments, the object that arrived first did not always have the smaller (or larger) optical size at the beginning of the scene. Brendel et al. (2012) reported that the effects of the threatening pictures on TTC estimation occurred with relatively long actual TTC values. Consequently, in Experiment 7, participants were instructed to view the entire approach scene before responding. Responses could not be entered until a "Respond Now" prompt was displayed after the approach scene ended. Trials with early responses were repeated and the repeated trials were used in the data analysis instead of the early responses (this occurred on 1.67% of the trials).

Procedure. Participants reported which object would reach or pass them first had the objects continued moving after they disappeared. To ensure processing of affective content, participants reported the name of the picture (e.g., angry, attacker) that would reach them first rather than its spatial position (left, right).

8.2.5.2 Results

Percentage accuracy and response time for non-tie approach events were analyzed separately with 2 (orientation) x 3 (picture pairing) repeated-measures ANOVAs. Response time for tie events were analyzed similarly but percentage accuracy was not applicable. Instead, two-tailed *t*-tests were conducted to determine whether participants selected angry face pictures or threatening scene pictures more often as arriving first than corresponding neutral stimuli.

Results of non-tie events in both experiments indicated that effects of picture pairing, orientation, and their interaction on mean response time and percentage accuracy were not significant (Faces: $Fs < 1.84$, $ps > .20$; Scenes: $Fs < 2.55$, $ps > .10$).

Results of tie events indicated that the effect of picture pairing on mean response time was not significant in either experiment. The results remained non-significant for tie and non-tie events when the data from both experiments were combined to increase statistical power. In addition, participants were not any more likely to select angry face pictures or threatening scene pictures as arriving earlier than neutral stimuli ($t < .13$). Finally, mean response time was greater for inverted faces ($M = 1.31$ s) compared with upright faces ($M = 1.17$ s), $F(1, 11) = 4.92$, $p = .0485$, $\eta_p^2 = .31$, but this inversion effect was not significant for scene pictures ($Fs < .57$, $ps > .46$).

Results of Experiments 7 and 8 were directly compared (separately for tie and non-tie scenes) with 2 (experiment) x 2 (orientation) x 3 (picture pairing) mixed ANOVAs. For non-tie scenes, mean response time was greater for scene pictures ($M = 1.66$ s) than faces ($M = 1.11$ s), $F(1, 22) = 30.34$, $p = .0001$, $\eta_p^2 = .58$. All other effects were nonsignificant ($Fs < 2.04$, $ps > .14$). For tie scenes, mean response time was greater for scene pictures ($M = 1.78$ s) than faces ($M = 1.24$ s), $F(1, 22) = 14.06$, $p = .0011$, $\eta_p^2 = .39$, and greater for the inverted than upright orientation, $F(1,22) = 4.85$, $p = .0384$, $\eta_p^2 = .18$. All other effects were nonsignificant ($Fs < 1.98$, $ps > .15$).

8.2.5.3 Discussion

Consistent with the results of the PM task in Experiment 4, emotional facial expression did not affect relative TTC estimates. In contrast to the results of the PM task in Experiment 5, threatening scene pictures did not affect relative TTC estimates. Thus, the task made a decisive difference and suggests that threatening pictures exert their influence on TTC estimation during the post-perceptual cognitive processing (e.g., cognitive extrapolation of motion after object disappeared) that was mandated by the PM paradigm. In contrast, the effect that inversion produces longer TTC estimates was consistent across paradigms suggesting that it is a perceptual effect.

8.2.6 General Discussion

When observers judged the TTC of objects that were about to collide with them (PM task), threatening pictures (i.e. frontal attacks) were judged to arrive earlier than neutral pictures (e.g., lamp) or friendly (e.g., baby) pictures (Experiment 4). However, this effect did not surface with threatening face pictures (i.e. angry emotional facial expressions) in the same PM task that was used for the threatening scene pictures – neither with Öhman, Lundqvist, and Esteves's (2001) schematic face stimuli (Experiment 6), nor with photographed faces (Experiment 5), even though faces were shown to elicit a threat advantage effect in a visual search task. When observers had to judge which of two simultaneously approaching objects would arrive earlier (relative TTC task), neither emotional facial expressions (Experiment 7) nor threatening scene pictures (Experiment 8) affected TTC estimates.

Previous studies of the "threat advantage" in visual search for faces have characterized the effect as being due to the perception of threat expressed by an emotional facial expression (e.g. Öhman, Lundqvist et al., 2001). Previous studies also showed a threat advantage effect in TTC estimation (e.g. Brendel et al., 2012), which is important when one wants to take action to evade the threat. Here we aimed to clarify whether the threat advantage effect depends on the potential of the threat (direct threat of overt attack pictures versus more ambiguous threat of facial expressions), and whether the effect depends more on the stimulus material (real faces versus abstract faces) or on the specifics of the task (visual search versus PM task versus relative TTC judgment). Our results clarify these issues.

8.2.6.1 Emotional effects are determined by threat potential

Both threatening scene pictures and threatening face pictures represent negative emotional content. If this emotional content underlies our previously reported effect of threatening scene pictures on TTC judgments (Brendel et al., 2012), threatening facial expressions should produce a similar effect. However, if our previous finding was due to the unequivocal threat, facial expressions may not modulate TTC estimates because their potential threat is merely implicit in the emotional expression. In other words, a threatening picture of a frontal attack shows the actual threat but a picture of an angry face implies a variety of possible outcomes including different degrees of threats and even non-threats. Based on the present results, we argue that the manifest threat is the primary variable producing a TTC effect. A facial expression may be characterized as threatening but the threat is not explicit and may range from an insult or rebuke to physical attack. Thus, the effects of a threatening face may also vary widely and may depend on the task (visual search vs TTC judgment).

The mechanism responsible for the different results between the emotional facial expressions and the threatening pictures in the PM task may be their different physiological arousing potential. As described in the introduction, threatening pictures of frontal attacks should activate the predator fear system, resulting in a heightened state of arousal that is meant to prepare the body for quick and exhaustive action. Threatening or angry faces should instead activate the social fear system that does not have the same physiological automaticity. Thus, if the emotional influence on TTC judgments depends on a heightened state of arousal, the effect would only appear for the threatening attack pictures but not for angry facial expressions. This is consistent with the previous finding that psychophysiological measures and event-related brain potentials are less modulated by emotional face expressions than emotional scenes (Wangelin et al., 2012).

Such an account may be related to the mechanism through which general time perception is affected by emotional pictures. This seems to depend on the level of arousal, with low-arousal stimuli triggering an attention effect, that is, temporal underestimation of negative pictures relative to positive ones, and high-arousal stimuli triggering an arousal effect, that is, temporal overestimation of negative pictures relative to positive ones (Angrilli et al., 1997). Maybe our facial stimuli elicited a medium state of arousal at which perception is either not affected at all or affected by both mechanisms at the same time, resulting in no net distortion.

Droit-Volet and Meck (2007) suggested that "the urgency of action for incoming events is one of the crucial factors affecting our perception of time" and took angry faces as an example of a stimulus implying especially urgent action. Within the context of facial expressions this is undoubtedly the case. However, compared to pictures of overt attacks, an angry face is signaling less urgency and definitely leaving more room for speculation and alternatives to immediate fight or flight reactions.

In addition, distortions of time perception due to facial stimuli seem to depend on processes of empathy and imitation (Droit-Volet & Gil, 2009). An impressive example of this is given by Effron, Niedenthal, Gil, and Droit-Volet (2006), who demonstrated that emotional face expressions led to distorted time perception only when participants were able to (unintentionally) imitate the emotional expressions. This speaks for a more indirect and flexible processing of emotional face expressions compared to threatening scenes. However, it contradicts our initial assumption of a more direct processing of the emotional face expressions based on a shorter presentation time needed to influence time-to-contact judgments compared to the presentation time needed with threatening scenes (Brendel et al., 2012). This need not be a contradiction but could reflect two different aspects of the processing: Emotional face expressions may be processed more quickly for the very reason (evolutionarily speaking) that an angry face is a less direct threat and needs more interpretation (more processing time after its initial detection and possibly some reinforcement by embodiment) than an overt attack. This second-step processing may be more easily disrupted by other task demands – or it may be irrelevant if the facial stimulus is intense and threatening enough to influence behavior, as was probably the case in our earlier study (Brendel et al., 2012) in which the angry face was presented on a very large projection screen (cinema effect).

In the context of our experiments, it may be easier in the relative TTC judgment task than in the PM task to direct attention to the edges of the two pictures (or to their relative sizes, etc.) and to ignore the content of the two pictures. Consequently, if an angry face needs some interpretational reinforcement (or an extremely large display) to be an effective threatening stimulus in our PM task, such interpretation should arise even less in the relative TTC task.

8.2.6.2 Emotional effects are determined by task specifics

Threatening scene pictures having an effect in the PM task but not in the relative TTC judgments can be explained by their different involvement of cognitive processes. The PM task putatively involves

cognitive motion extrapolation and requires a timed response. In contrast, our relative TTC task was less dependent on cognitive processes because the viewing time of the approaching objects was only 1 s, and the participant's response occurred shortly after the target disappeared (see Tresilian, 1995). Our results suggest that not only is threat the driving force but it also has to have a chance to manifest itself in the cognitive extrapolation that occurs between visual stimulus offset and collision time (in a PM task). More generally, if one assumes that the evaluation of threat in a stimulus can involve cognitive assessment (Brendel et al., 2012), influences of affective content may depend on the degree to which the task involves cognitive processes.

Another possible explanation for the absence of an effect of emotional content on relative TTC judgments may be their dependency on spatial attention. At least for emotional face expressions it has been shown that "all brain regions responding differentially to emotional faces, including the amygdala, did so only when sufficient attentional resources were available to process the faces" (Pessoa, Kastner, & Ungerleider, 2002, p. 31). Especially concerning spatial attention, the emotional modulation of a face-specific early event-related brain potential (ERP) positivity is diminished when foveally presented stimuli are unattended and the emotional modulation of the ERP positivity is even absent when peripherally presented stimuli are unattended (Eimer & Holmes, 2007). In addition, amygdala and anterior cingulate cortex reactivity to emotional faces are greater when the focus of attention is directed to the face stimuli compared to when the emotional faces are just present on the display while attention is directed to objects placed besides the faces (Klumpp, Angstadt, & Phan, 2012).

In our relative TTC judgment task, two stimuli were presented simultaneously side by side and were thus presented more peripherally than the one stimulus in the PM task. In addition, the relative judgment task may direct attention away from the content of each picture and toward the pictures' edges or relative motions and may leave less attentional resources for the processing of the images' content. This task may even involve a more deliberate ignoring of the pictures' content than the PM task; ignoring angry faces has been shown to reduce sensitivity to the previously ignored face's expression (Gómez-Cuerva & Raymond, 2011). The same dependency on attention may occur with non-facial pictures, rendering the effect of the threatening scene pictures non-significant. In the PM task (Experiments 4 and 5), it may be easier for participants to ignore the emotional content of the faces and focus on the edges of

the face, and more difficult to ignore the emotional content in the pictures when it comprises the entire picture.

8.2.6.3 Discrepancy between current results and those of Brendel et al. (2012)

Although we replicated our previously reported effect of threatening scene pictures on TTC estimates (Brendel et al., 2012), we did not replicate the (small) effect of emotional facial expression. We consider several reasons for this apparent discrepancy. First, stimuli in the previous study – which were presented stereoscopically on a large screen (78-deg diagonal), likely resulted in greater arousal than the current stimuli – which were presented non-stereoscopically on a smaller screen (50-deg diagonal). This account is aligned with our previously reported supposition that the effect of angry faces was smaller than the effect of threatening pictures due to relatively lower arousal (as indicated by significantly lower arousal ratings on the SAM scale). The smaller, non-stereoscopic displays in the current study may have resulted in even lower arousal, eliminating the face effect. If validated, this account would suggest that arousal is an important component of the threat effect.

Second, the longer presentation duration in the current study (3 s) provided more time for the facial expression to be processed and thus be influential, but at the same time provided more time for observers to resolve ambiguities regarding threat than the durations in our previous study (200 ms, 800 ms). With no change in the face over the course of 3 s, the observer's perceived likelihood of a manifest threat may have decreased, ultimately eliminating the face effect. This account is aligned with our supposition that manifest threat rather than emotional valence underlies the threat effect.

Finally, the longer TTC values in the current study (.75 s, 1.5 s, 3 s) required longer mental extrapolation times than those in our prior study (.6 s, .8 s, 1 s). This putatively greater cognitive demand may have interfered with the processing, and ultimately the influence, of the angry face. When we reanalyzed the data using only the .75-s TTC condition, the difference between the angry face and neutral or happy face still did not emerge, rending this account less viable.

8.2.7 Conclusions

Our results add to the growing number of studies which indicate that TTC judgments of approaching objects are not based solely on TTC information available in the optical expansion pattern, and that the affective information presented in the optical pattern can influence such judgments. We show further that not all affective information has the same effect, and whether an effect occurs at all may depend on the

task and the degree to which the task involves cognitive processes. Whereas threat carried by scene pictures of overt attacks may affect TTC judgments, threat carried by pictures of facial expressions may not. We propose that it is the picture's explicit potential of the threat per se and not only the emotional valence of the picture that underlies the effect of threatening pictures on TTC judgments. Moreover, this effect occurs only when the task allows sufficient cognitive processing of the stimuli. The effect of threatening pictures occurred in the PM task, which putatively required cognitive motion extrapolation, but not in a relative TTC judgment task which was designed to rely less on cognitive processes. The distinction between the effects of threatening pictures and emotional expressions may reflect the different underlying fear systems and associated physiological mechanisms and demands. Whereas the predator fear system has to prepare immediate and rapid evasion responses, the social fear system must assess a range of threatening outcomes and appropriate responses.

8.3 Disentangling arousal, valence and fear[9]

8.3.1 Abstract

Recently, responses to looming visual stimuli have been shown to depend on the emotional content of the stimulus. A threatening stimulus is judged to arrive sooner compared to a neutral stimulus, possibly buying the organism time to prepare defensive actions. Here, we explored the underlying mechanism. We found that time-to-contact judgments of threatening pictures did not differ from those of highly arousing pleasant pictures (Experiment 9), suggesting that arousal, not fear, modulates the perception of looming. Specific fear modulated the effects of arousal (Experiment 10): Spider-fearful participants' judgments showed a threat advantage effect while non-fearful participants' judgments were less affected by emotional content. In Experiment 11, arrival times were less overestimated when pictures induced arousal. However, this effect interacted with the valence of the stimulus: For unpleasant stimuli, arousal induced shorter time-to-contact judgments whereas for pleasant stimuli, an inverted U-shaped relation was found. We propose a general content effect to explain the overestimation with neutral pictures: Pictorial content may draw visual attention to inner contours instead of to the outer edges of the picture. This could delay time-to-contact judgments according to the known size-arrival effect. Our results add to the growing literature examining affective influences on visual perception.

8.3.2 Introduction

The ability to avoid a threatening moving object is essential for survival. Biological systems have evolved to visually detect such objects: Objects approaching on a direct collision course result in optical looming, a stimulus that elicits evasive or defensive actions in animals and humans (Ball & Tronick, 1971; Schiff, 1965). Brendel et al. (2012) and Vagnoni et al. (2012) showed that responses to such looming stimuli are modulated by the emotional relevance of the approaching object. Pictures of frontal attacks and angry facial expressions produced shorter time-to-contact (TTC) estimates than neutral pictures (Brendel et al., 2012) just as did pictures of snakes and spiders compared to butterflies and rabbits used by Vagnoni et al. (2012). Vagnoni et al. further showed that ratings of fear for threatening stimuli correlated with shorter

TTC estimates. However, there are several unresolved issues in the studies by Brendel et al. (2012) and Vagnoni et al. (2012) that we attempt to address here.

First, in both studies, threat could have worked by way of the arousal it produced or by way of its emotional valence, namely fear. With their third experiment, Vagnoni et al. (2012) demonstrated that static priming images do not affect the TTC judgments to a subsequent neutral looming stimulus. They interpreted this lack of priming as indicating that the modulation of TTC judgments is due to the moving stimuli's threat value and not simply to a heightened state of arousal. However, arousal and threat have not been properly disentangled *in* the looming stimulus yet. Thomas, Jackson, and Raymond (2014) recently showed that an emotional effect on working memory is object-specific; the same may be the case for emotional effects on perception. In the current study, we therefore compared TTC judgments of threatening pictures to judgments of pleasant pictures that induced comparable levels of arousal (Experiment 9). We also measured the relationship between TTC estimates and arousal as measured by skin conductance responses (Experiment 10), and the interaction effect between arousal and valence on TTC estimates (Experiment 11).

Second, previous studies have not investigated whether the effect of threat was due to *specific* fear rather than to non-specific arousal, though the analysis of fear ratings in Vagnoni et al. (2012) speaks for a specific effect. If the threat effect is due to a fear response to a particular stimulus rather than to general heightened arousal, TTC estimates to threatening stimuli should be shorter for participants who fear such stimuli compared to participants who do not show such response. To address this issue, we compared TTC judgments of approaching spider stimuli between groups of participants differing in their fear of spiders (Experiment 10).

Third, Brendel et al. (2012) reported an unexpected finding in which stimuli without emotional content ("empty" faces) were judged to arrive as early as those with threatening content (angry faces). DeLucia et al. (2014) replicated this effect with empty colored squares but not with abstract or photographed faces. They proposed that the content of a stimulus distracts the observer from the task, leading to longer TTC estimates compared to stimuli that do not require interpretation. However, the effect of the empty face of Brendel et al. (2012) could have been emotional, since some participants described this stimulus as the most disturbing one. In addition, distraction should have an undirected effect but the variability of the TTC estimates was not analyzed in Brendel et al. (2012) and Vagnoni et

al. (2012). A more specific effect of content may occur when observers attend to contours of objects within the picture rather than to the picture's frame. Accordingly, TTC estimates based on inner contours would be longer than estimates based on the larger frame edges, an instantiation of the size-arrival effect (DeLucia, 1991). In the size-arrival effect, a small near object and a large far object approached the observer at the same speeds, and participants reported that the larger object would hit them first. For stimuli without content (empty squares), inner contours that draw attention are absent and such stimuli would lead to shorter TTC estimates than stimuli with content. This size-arrival effect is affected by attentional processes. For example, DeLucia (1991) reported that when arrows or ground-intercept cues were added to approaching stimuli, the size-arrival effect could be eliminated but only when observers were instructed to attend to those cues. To examine the effects of pictorial content and emotional content, we compared TTC judgments of pictures with varying affective values to judgments of colored squares, including an analysis of the TTC judgments' standard deviations (Experiment 11).

Finally, Brendel et al. (2012) reported that the effect of threat on TTC estimates was small and depended on presentation duration. Thus, it seems important to validate these effects and elucidate boundary conditions regarding both the experimental parameters and the affective value of the stimuli. In this paper, we concentrate on investigating the role of the emotional content and individual differences in the emotional reaction to the stimuli.

8.3.3 Experiment 9: Pleasantly arousing

In this experiment, we examined if the threat advantage effect also would surface when threatening pictures are compared to pleasantly arousing instead of neutral pictures. If threat induced shortened TTC judgments, the same effect should surface in comparison with highly arousing pleasant pictures. If unspecific arousal induced shortened TTC judgments, all arousing pictures should produce comparable judgments regardless of their threat content.

8.3.3.1 Materials and methods

Participants

Fourteen women and four men (mostly students) between 19 and 27 years of age (M = 22.4; SD = 2.46) participated for course credit or payment. All had normal or corrected-to-normal visual acuity (minimally 100 seconds of arc on a Landolt C test) and normal stereovision (minimally 100 seconds of arc on a

Titmus test programmed for the virtual reality laboratory following the specifications given in Bennett & Rabbetts, 1998, pp. 201-202). The research in this and the following experiments was conducted according to the principles expressed in the Declaration of Helsinki; informed consent was obtained from all subjects.

Stimuli

Twelve images from the International Affective Picture System (IAPS, Lang et al., 2005) served as stimuli. The three threatening pictures (frontal attacks) used in our earlier experiments (Brendel et al., 2012), were compared with nine pleasant pictures (erotica and money) instead of the nine neutral pictures used earlier, maintaining the proportion of 25% threatening pictures. Based on IAPS arousal ratings (averages of men and women), we chose the most arousing pleasant pictures that were approximately equivalent to the threatening pictures in terms of their depth impression (i.e. showing relatively close, picture-filling people or objects). For details see Table 4.

Table 4.   Short description of the **s**timuli and their mean arousal and valence ratings (averages of men and women) used for the three experiments of Section 8.3, retrieved from Lang et al. (2005).

Experiment	Category	Picture content	IAPS		
			Number	Mean arousal	Mean valence
1	Attack	Snarling Pit Bull	1300	6.79	3.55
		Attacker with knife	6510	6.96	2.46
		Biting snake	1120	6.93	3.79
	Pleasant	Nude erotic couple	4311	6.67	6.66
		Nude erotic couple	4659	6.93	6.87
		Nude erotic couple	4660	6.58	7.4
		Nude erotic couple	4677	6.19	6.58
		Nude erotic couple	4687	6.51	6.87
		Nude erotic couple	4695	6.61	6.84
		Pile of gold bars	8500	5.60	6.96
		Scattered banknotes	8501	6.44	7.91
		Pile of banknotes	8502	5.78	7.51
2	Attack	Snarling Pit Bull	1300	6.79	3.55
		Attacker with knife	6510	6.96	2.46
		Biting snake	1120	6.93	3.79
	Spider	In its net			
		On fingertip	n. a.	n. a.	n. a.
		On stony ground			
	Pleasant	Nude erotic couple	4660	6.58	7.40
		Nude erotic couple	4677	6.19	6.58
		Scattered banknotes	8501	6.44	7.91

	Neutral	Man	2190	2.41	4.83
		Mushrooms	5500	3.00	5.42
		Lamp	7175	1.72	4.87
3	Unpleasant, high arousal	Snarling Pit Bull	1300	6.79	3.55
		Kiss of mutilated face	2352.2	6.25	2.09
		Baby tumor	3170	7.21	1.46
	Unpleasant, medium arousal	Sad children	2703	5.78	1.91
		Crying boy	2900.1	4.61	2.56
		Man at life support system	3230	5.41	2.02
	Unpleasant, low arousal	Elderly woman	2590	3.93	3.26
		Garbage	9290	4.40	2.88
		Pollution	9341	4.50	3.38
	Neutral, very low arousal	Basket	7010	1.76	4.94
		Lamp	7175	1.72	4.87
		Male face	2190	2.41	4.83
	Pleasant, low arousal	Boys reading	2222	4.08	7.11
		Children	2387	3.97	7.12
		Smiling boy	2900.2	4.52	6.62
	Pleasant, medium arousal	Father with baby	2165	4.55	7.63
		Kiss on cheek	2352	4.99	6.94
		Cuddling couple	4625	5.05	6.40
	Pleasant, high arousal	Nude erotic couple	4659	6.93	6.87
		Bungee jumper	8179	6.99	6.48
		Rollercoaster	8499	6.07	7.63
	Flat Color	White Grey Skin color	n. a.	n. a.	n. a.

Note. All pictures with borders were cropped so that the motive filled the picture, keeping aspect ratio constant.

Design and procedure

The experimental setup, design, and procedure were identical to that described in (Brendel et al., 2012) except for the partially different stimuli. Displays were presented stereoscopically (24 frames/s for each eye) on a 2.60 m wide x 1.95 m high rear-projection screen in a darkened room (F10 AS3D projector and Xpand shutterglasses from VRlogic). The stimuli were programmed in virtual space (Vizard 3.0 from Worldviz); one virtual m corresponded to one real m. A chin rest stabilized head position at a 2 m viewing distance.

In a prediction-motion paradigm, a threatening or pleasant picture (emotional content) approached the participant through a tunnel at a constant velocity for 200 or 800 ms (presentation time). Participants were instructed to extrapolate the picture's motion after it disappeared and to press a button when the picture would have collided with them. If they did not respond within a time window from the picture's disappearance up to 1 s after actual TTC, the trial was repeated until a response was obtained

within that time window. (This happened in 0.6 % of all trials; the worst participant repeated 9 out of 288 trials.) We calculated TTC estimates as the time from the picture's disappearance to the participant's button press. To assess several estimates per picture while discouraging participants from making their judgments on the basis of simple heuristics (e.g., a single stimulus property such as image size), we varied the stimuli on several dimensions, such as 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 1000 ms). The design was fully crossed (12 pictures × 2 presentation times × 2 widths × 2 velocities × 3 TTCs). Each participant viewed 288 trials in a fully randomized order, starting each trial at their own pace. Three short breaks allowed the participants to relax between 4 equal-sized blocks. Twelve training trials with feedback (a prompt of the estimation error in ms and whether it was too short or too long), and with a different photograph that was not used as an experimental stimulus, preceded the experiment. Participants needed between 11 and 20 minutes to complete all trials.

After all TTC judgments were made, we assessed arousal ratings in the same manner as these ratings were assessed for the IAPS catalogue, that is, by showing each picture again for 6 s, and asking the participants: "How do you feel when you look at this picture?". Answers were given with self-assessment manikins (Lang, 1980). This scale consists of five line drawings depicting the affective states. Participants can choose one of the manikins or an intermediate state, resulting in a 1 (calm) to 9 (aroused) point scale.

Data analysis

We averaged each participant's TTC estimation errors (calculated as estimated TTC minus actual TTC) and arousal ratings for each picture category, and subjected mean estimation errors and arousal ratings to further analyses. For all statistical analyses for this and the following experiments we chose the alpha-level 0.05 and we report Huynh-Feldt corrections where appropriate.

8.3.3.2 Results

Estimates of TTC as a function of actual TTC are shown in Figure 10. We found no effect of threat when all pictures were highly arousing: Threatening pictures were judged to arrive on average 14 ms late (SD = 174 ms) whereas pleasantly arousing pictures were judged to arrive on average 3 ms early (SD = 181 ms). This difference did not reach statistical significance, $t(17) = 1.89$, $p = .08$, CI = -0.002 to 0.036.
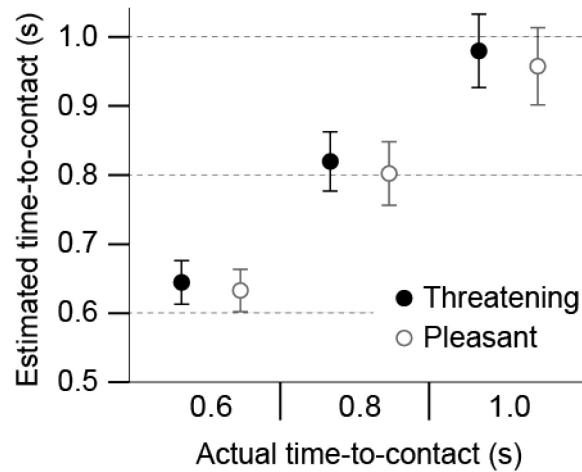
Figure 10. Average estimated TTC as a function of actual TTC for threatening and pleasant pictures in Experiment 9. Error bars represent standard errors of the means

In earlier research, shortened TTC judgments for threatening compared to neutral pictures surfaced only at the longer presentation time (Brendel et al., 2012). Thus, we analyzed the data again, with TTC estimation errors averaged separately for both picture categories at both presentation times. A 2 (picture category) x 2 (presentation time) repeated measures ANOVA indicated no significant effect of picture category, $F(1,17) = 3.55$, $p = .08$, and no significant interaction between picture category and presentation time, $F(1,17) = 2.90$, $p = .11$. A shorter presentation time (200 ms) led to an average underestimation of TTC by 39 ms (SD = 176 ms), whereas a longer presentation time (800 ms) led to an average overestimation by 42 ms (SD = 193), $F(1,17) = 13.93$, $p < .01$, $\eta_p^2 = .45$. A similar trend was observed in two of the three experiments reported earlier (Brendel et al., 2012).

Our participants rated threatening pictures to be more arousing (M = 6.44, SD = 1.44) than pleasant pictures (M = 4.49, SD = 1.32), $t(17) = 8.43$, $p < 0.001$, CI = 1.47 to 2.45. Still, the pleasant pictures in the current study received significantly higher arousal ratings than the neutral ones (M = 3.38, SD = 1.24) in our former paper (Brendel et al., 2012), $t(36) = 2.66$, $p = .01$, CI = 0.26 to 1.95, whereas the threatening pictures were not rated significantly different in the current study and in our former paper (M = 7.22, SD = 1.38), $t(36) = 1.69$, $p = .10$, CI = -1.70 to 0.15.

To test for correlations between arousal ratings and TTC estimates across stimuli, we calculated Spearman's rank order correlations on the mean values for each picture within each participant. These correlations (Fisher z-transformed) did not differ significantly from 0, mean $r = .11$, $t(17) = 1.50$, $p = .15$, CI = -0.05 to 0.27.

8.3.3.3   Discussion

TTC judgments of threatening pictures did not differ significantly from those of pleasantly arousing pictures. Thus, arousal by itself and not the emotional valence of fear seems to modulate TTC estimates.

However, even though all pictures were selected to be highly arousing according to IAPS ratings, our participants rated threatening pictures as more arousing than pleasant pictures. Such a discrepancy between IAPS and participants' ratings also occurred in other studies and has been ascribed to differences in the rating procedure (Olofsson, Nordin, Sequeira, & Polich, 2008, p. 259). The lack of a correlation between the arousal ratings and the TTC judgments contradicts a simple arousal effect. One possibility is that the arousal differences were not large enough for a correlation to surface. Another possibility is that the differences in our participants' explicit ratings do not mean much in terms of their physiological arousal. That is, minimal arousal differences within the picture sample may have seemed larger than they would have if we had included a neutral condition. Yet another alternative is that the greater proportion of pleasant pictures may have led to habituation, which was then reflected in lower arousal ratings that were assessed after all TTC judgments had been made.

In essence, after this experiment, we can conclude that a reduced arousal contrast between threatening and non-threatening pictures abolishes the emotional modulation of TTC judgments. We aimed to better control for the different effects of fear and arousal in Experiment 10 and of arousal and valence in Experiment 11.

8.3.4   Experiment 10: Spider fearfuls

In this experiment, we compared all three categories: threatening, pleasantly arousing, and neutral pictures. To more reliably assess the arousal induced by the pictures, we measured skin conductance responses (SCRs) during the experiment, in addition to obtaining arousal ratings afterwards. SCRs are a measure commonly used as an indicator of arousal (Dawson, Schell, & Filion, 2007). We also included a group of spider-fearful participants and spider pictures as a fourth stimulus category. If unspecific arousal really was the single source of the threat advantage effect, then fear of spiders should not modulate the effect of arousal.

8.3.4.1 Materials and methods

Participants

Thirty-six women and two men aged 19 to 28 years (M = 22.1, SD = 2.25) participated for course credit or payment. Visual acuity and stereovision were tested as in Experiment 9. We screened 701 students at the University of Mainz using the German version of the "Fear of Spiders Questionnaire" (Pössel & Hautzinger, 2002). Scores on this questionnaire range between 14 and 98, with lower scores indicating less fear of spiders. Scores of 50 or more were reached by 20% of the validation sample. We recruited 19 students scoring highest for our spider fearful group (scores between 52 and 91, M = 68.4, SD = 9.6) and 19 others scoring lowest for the control group (scores between 14 and 47, M = 21.0, SD = 8.5). In addition, we matched age and sex of both groups' participants.

Stimuli

Three of the pleasantly arousing pictures from Experiment 9 and three of the neutral pictures used by Brendel et al. (2012) were compared with the three threatening pictures used in both experiments. Because the pictures of spiders available in the IAPS did not have the same range of contrast, sharpness, and depth impression as the first nine pictures, we obtained suitable pictures of spiders from the internet. For details see Table 4.

Design and procedure

The experimental setup, design, and procedure were identical to Experiment 9 except for the following changes: For the skin conductance measurement it was necessary to include fixed intervals between the trials instead of giving the participants the chance to repeat a trial when they missed it. Thus we extended the time window for a response to up to 3 seconds after actual TTC, and each trial was repeated once to increase the probability of getting at least one judgment per participant and combination of the parameters.

To keep the duration of the session within reasonable limits (participants needed between 28 and 35 minutes to complete all trials), we omitted the shorter presentation time that had not been effective in Brendel et al.'s (2012) experiments and only showed the approaching picture for 800 ms. Physiological markers of arousal are reported to peak between 3 and 6 s after stimulus onset (Lui, Penney, Schirmer, & Meck, 2011). Thus, we used slightly longer times from disappearance to collision (800, 1000, or 1200

ms) to ensure a substantial effect of the emotional content while refraining from greatly lengthening the duration of the session. The design was again fully crossed (12 pictures × 2 widths × 2 velocities × 3 TTCs × 2 repetitions).

Measurement of electrodermal activity

We recorded skin conductance bipolarly using Ag/AgCl electrodes (1 cm diameter; Marquette Hellige, Freiburg, Germany) filled with 0.05 M NaCl electrolyte connected to a constant voltage system (0.5 V). The non-dominant hand was used, and the leads were placed at the thenar and hypothenar eminences. Skin conductance data were digitized at 10 Hz by a conventional PC and saved for offline analysis.

We presented the 288 trials per participant in 3 blocks separated by short breaks. Skin conductance measurement started 5 seconds before the first trial of each block and continued 20 seconds after the last trial of each block. Within each block, a random duration between 2 and 6 seconds elapsed before each new photograph was presented.

Data analysis

We averaged TTC estimates of repeated trials. In 39 trials (0.71%) participants did not react within the 3 s time-window after the picture disappeared. Such missed trials happened in both groups in all four picture categories. We used only the response of those trials' repetitions in the analysis (at least one valid judgment was recorded for all identical pairs of trials). Again, we calculated TTC estimation error as actual minus estimated TTC and averaged within each picture category.

Skin conductance was successfully recorded from 32 participants. To reliably quantify the amplitude of stimulus-related SCRs with our very short interstimulus intervals (i.e., substantially below 10 s), we decomposed the skin conductance tracing into tonic and phasic components with an individually fitted template of a discrete SCR for each participant (Lim et al., 1997). This procedure is explained in detail by Gamer and Berti (2012) and allowed us to determine SCRs that occurred with a latency of 1 to 3 s after stimulus onset. We log-transformed the amplitudes of these responses to reduce the skew of the amplitude distribution (Venables & Christie, 1980), and averaged across trial repetitions (trials with missing TTC estimates were excluded from the averages). To reduce the effects of different individual skin conductance reactivity, we normalized the amplitudes by dividing individual response amplitudes by the maximum amplitude of the particular participant.

Mean TTC estimation errors for each picture category and their standard deviations, as well as mean arousal ratings and mean SCRs, were analyzed in separate 4 (picture category) x 2 (spider phobia) ANOVAs for repeated measures with spider phobia as the between-groups factor.

8.3.4.2 Results

Spider fearfuls judged spider pictures and attack pictures (but not pleasant pictures) to arrive earlier than neutral ones. In contrast, the control group judged spider pictures to arrive later than neutral pictures (see Figure 11). These results are based on the following statistical analyses: Neither picture category nor fear of spiders had a main effect on mean estimation errors or SDs, all $F < 1.40$, $p > .25$. The interaction between both factors was significant for mean estimation errors, $F(3,108) = 7.82$, $\varepsilon = .85$, $p < .001$, $\eta_p^2 = .178$, but not for SDs, $F < 1$. To decode the significant interaction, we ran two separate ANOVAS with the repeated measures factor picture category for each experimental group. The effect of picture category on mean estimation errors was significant for both groups, control group: $F(3,54) = 6.08$, $\varepsilon = .98$, $p < .01$, $\eta_p^2 = .25$; spider-fearful: $F(3,54) = 3.61$, $\varepsilon = .79$, $p = .02$, $\eta_p^2 = .17$, but the direction of the effect was quite different as shown by the significant contrasts marked in Figure 11.
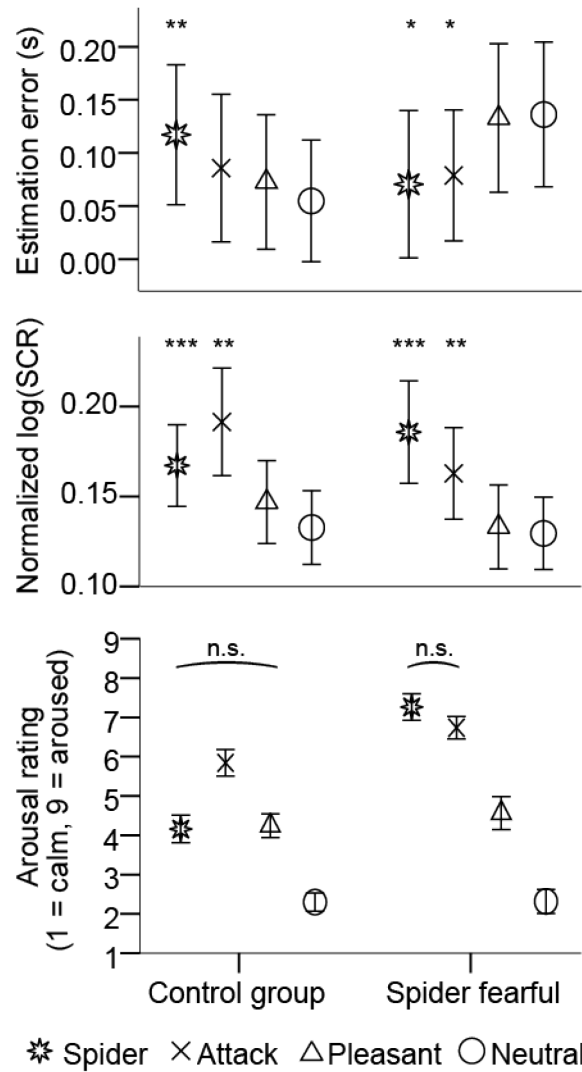
Figure 11. Experiment 10. Upper panel: average TTC estimation errors (estimated TTC minus actual TTC), middle panel: average SCR amplitudes, lower panel: average arousal ratings for the picture categories in the two experimental groups in Experiment 2. * $p < .05$, ** $p < .01$, *** $p < .001$, significantly different TTC estimation errors or SCRs compared to neutral reference category as indicated by ANOVA contrasts, n.s.: the only two contrasts for which arousal ratings were not statistically significant, all other arousal rating contrasts $F > 22$, $p < .001$. Error bars represent standard errors of the means

Attack pictures received higher arousal ratings than pleasant pictures which in turn received higher arousal ratings than neutral pictures in both groups. Spider fearfuls rated spider pictures as arousing as attack pictures and the control group rated spider pictures as arousing as pleasant pictures (see Figure 11). These results are based on the following statistics: Arousal ratings differed significantly between picture categories, $F(3,108) = 80.86$, $\varepsilon = 1$, $p < .001$, $\eta_p^2 = .69$, and both experimental groups $F(1,36) = 12.09$, $p < .01$, $\eta_p^2 = .25$. The interaction between group and picture category was significant, $F(3,108) = 12.63$, $\varepsilon = 1$, $p < .001$, $\eta_p^2 = .26$. Separate ANOVAs with the repeated-measures factor picture

category revealed that picture category had a significant effect on arousal ratings, both in the control

group: $F(3,54) = 40.58$, $\varepsilon = 1$, $p < .001$, $\eta_p^2 = .69$, and in spider-fearfuls: $F(3,54) = 49.85$, $\varepsilon = .97$,

$p < .001$, $\eta_p^2 = .74$. Non-significant contrasts are marked in Figure 11.

Spider and attack pictures elicited greater SCRs than neutral pictures, whereas pleasant pictures

did not elicit significantly different SCRs than neutral pictures. This was statistically indicated by a

significant main effect of picture category, $F(3,90) = 10.65$, $\varepsilon = .73$, $p < .001$, $\eta_p^2 = .26$ (significant

contrasts are marked in Figure 11). Fear of spiders had no main effect on SCRs and did not interact with

picture category, both $F < 1.81$, $p > .15$.

To analyze correlations between arousal and TTC, we calculated Spearman's rank order

correlations between all 144 SCR and TTC values (averages of repeated trials) within each participant.

We did the same for the arousal ratings of each picture and the corresponding mean TTC values. These

correlations (Fisher z-transformed) differed significantly from 0 for the SCRs but not for the arousal

ratings in both spider-fearfuls and the control group (spider fearfuls, SCRs: mean $r = -.24$, $t(15) = 3.63$,

$p < .01$, CI = -0.39 to -0.09, spider fearfuls, arousal ratings: mean $r = -.15$, $t(18) = 1.38$, $p = .19$,

CI = -0.38 to 0.08, control group, SCRs: mean $r = -.12$, $t(15) = 2.69$, $p = .02$, CI = -0.21 to -0.02, control

group, arousal ratings: mean $r = .01$, $t(18) = 0.18$, $p = .86$, CI = -0.13 to 0.15).

8.3.4.3 Discussion

Spider-fearful observers judged spider pictures and attack pictures to arrive earlier than neutral and

pleasant pictures. In contrast, the control group judged only spider pictures to arrive later than neutral

pictures. On average, in both groups, TTC estimation errors were negatively correlated with SCRs across

all stimuli. Subjective arousal ratings mostly reflected the pattern of the SCRs except for pleasant

pictures; the latter were rated as more arousing than neutral pictures, but SCRs did not reflect this

difference.

The results show that effects of arousal on TTC judgments are modulated by specific fears. Non-

spider-fearfuls showed a reversed difference between spider pictures' and neutral pictures' judged arrival

times compared to spider-fearfuls. The modulation extended beyond stimuli depicting the specific feared

object category: Non-spider-fearfuls did not even judge more generally threatening pictures to arrive

earlier than neutral ones, while attack pictures were nevertheless the most arousing stimuli for this group

in terms of ratings and skin conductance measurements.

Assuming that the TTC estimates of our non-fearful participants were generally less emotionally affected, their longer estimates for spider pictures may have resulted from the relative small size of the spiders' bodies (if one discounts the thin and less visible legs) on the pictures compared to the relatively larger objects on the other photographs. Such a size-arrival-effect (DeLucia, 1991) due to judgments based on the photographed object sizes instead of the flat pictures' borders would even strengthen the threat advantage effect found in the spider fearful group: They judged the spiders to arrive earliest *even though* those were the smallest objects on the pictures. Possibly facilitating this effect, spider phobic individuals overestimate the size of living spiders (Vasey et al., 2012) and Hosking and Crassini (2010) found an effect of familiar size in addition to the size-arrival-effect in a prediction-motion paradigm.

8.3.5   Experiment 11: Arousal x valence

We conducted Experiment 11 to look more closely at the relationship between arousal and valence. To do so, we systematically manipulated the degree of arousal within sets of pleasant and unpleasant stimuli. In addition, we included colored rectangular planes to obtain a better estimate of optimum performance in this task and to examine the general effect of pictorial content.

8.3.5.1   Materials and methods

Participants

Eighteen women and twelve men (mostly students) aged 19 to 38 years (M = 22.9; SD = 4.38) participated for course credit or payment. Visual acuity was tested as in Experiment 9.

Stimuli

We used eight stimulus categories with three individual pictures in each category. We chose IAPS pictures by dividing the complete IAPS arousal ratings (averages of men and women) into four ranges, very low (< 3.12), low (> 3.12 and < 4.54), medium (> 4.54 and < 5.94) and high (> 5.94), and the complete IAPS valence ratings into three ranges, low (< 3.65), medium (> 3.65 and < 6.00), and high (> 6.00). The combination of very low arousal and medium valence provided the neutral pictures, which were three of those used in Brendel et al. (2012). In addition, we used three pictures from each of the six combinations of the remaining arousal and valence ranges. Colored rectangular planes served as control category. For details see Table 4.

<u>Design and procedure</u>

The experimental setup, design, and procedure were identical to Experiment 9 except for the following changes: For organizational reasons in the laboratory, the stimuli were presented on a 0.92 m wide x 0.52 m high computer screen at 0.5 m viewing distance without stereo projection. On a smaller screen, pictures might have had less emotional impact compared to the large projection screen used in Experiments 9 and 10. Thus, we used an even longer presentation time (1 s) and occlusion times (1 s, 1.5 s, or 2 s) to strengthen the emotional effect. We chose those values to approximate the reported peak of physiological arousal between 3 and 6 s after stimulus onset (Lui et al., 2011). At the same time, including our response time window of up to 1 s after actual TTC, we did not want to exceed 4 s, above which effects of emotional stimuli on time perception disappear (Droit-Volet & Gil, 2009, p. 1945).

The design was again fully crossed (24 pictures × 2 widths × 2 velocities × 3 TTCs). Participants needed 15 to 30 minutes to complete all trials at their own pace, while in total 133 (1.5%) of all trials were repeated; the worst participant repeated 21 out of the 288 trials. After the TTC judgments, we assessed valence ratings in addition to arousal ratings as described for Experiment 9. Valence was rated on a 1 (unhappy) to 9 (happy) scale depicted by self-assessment manikins (Lang, 1980).

<u>Data analysis</u>

Again, we calculated TTC estimation errors as estimated TTC minus actual TTC and averaged those values and the arousal ratings for each picture category. Mean estimation errors, SDs of estimation errors, and mean arousal and valence ratings were each subjected to an 8 (picture category) repeated-measures ANOVA.

8.3.5.2 Results

Picture category had a significant effect on mean TTC estimation errors, $F(7,203) = 3.61$, $\varepsilon = 1$, $p < .01$, $\eta_p^2 = .11$, on mean arousal ratings, $F(7,203) = 36.27$, $\varepsilon = .56$, $p < .001$, $\eta_p^2 = .56$, and on mean valence ratings, $F(7,203) = 93.46$, $\varepsilon = .41$, $p < .001$, $\eta_p^2 = .76$, but not on SDs of TTC estimation errors, $F < 1$. Significant contrasts of mean TTC estimation errors, arousal ratings, and valence ratings are marked in Figure 12.
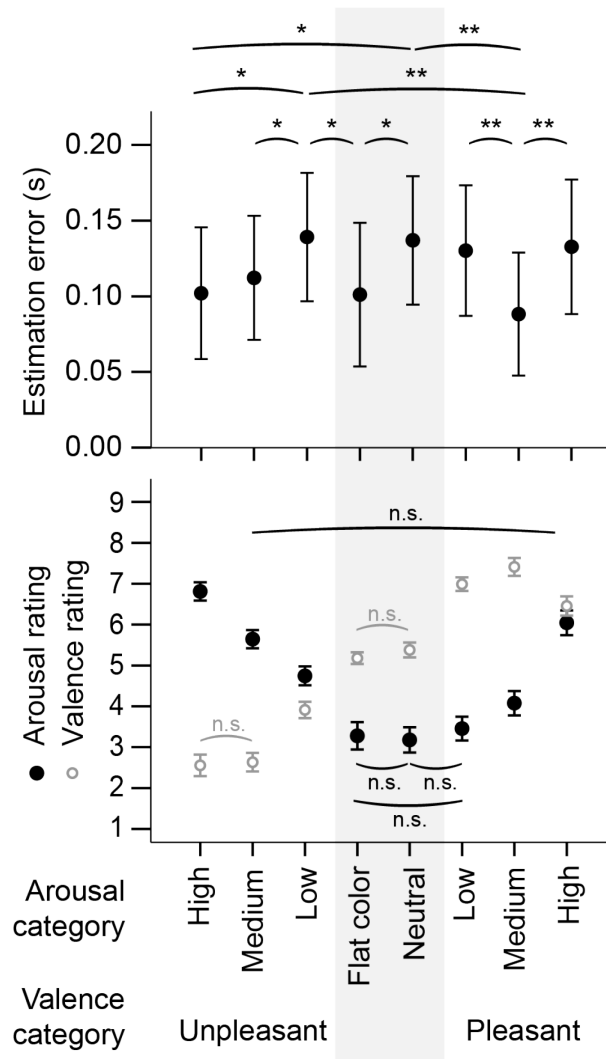
Figure 12. Experiment 11. Upper panel: average TTC estimation errors (estimated TTC minus actual TTC) with all statistically significant contrasts marked as * $p < .05$, ** $p < .01$, *** $p < .001$, lower panel: average arousal (1 = calm, 9 = aroused) and valence (1 = unhappy, 9 = happy) ratings for the picture categories with all statistically non-significant contrasts marked as n.s. Error bars represent standard errors of the means

To specifically test for the effects of valence and arousal on mean estimation errors, we conducted a 2 (valence) x 3 (arousal) repeated measures ANOVA only with the six pleasant and unpleasant categories. Valence had no main effect on estimation errors, $F < 1$, whereas the main effect of arousal was statistically significant, $F(2,58) = 6.69$, $\varepsilon = 1$, $p < .01$, $\eta_p^2 = .19$. Most importantly, polynomial contrasts of the significant valence x arousal interaction, $F(2,58) = 4.57$, $\varepsilon = 1$, $p = .01$, $\eta_p^2 = .14$, revealed a quadratic trend for responses to pleasant pictures, $F(1,29) = 4.80$, $p = .04$, $\eta_p^2 = .14$, and a linear trend for responses to unpleasant pictures, $F(1,29) = 4.35$, $p = .05$, $\eta_p^2 = .13$.

8.3.5.3 Discussion

The more arousing an unpleasant picture, the sooner it was judged to arrive. In contrast, the TTC of pleasant pictures was least overestimated at a medium level of arousal. All optimum-performance categories, the medium and high-arousing unpleasant pictures and the medium-arousing pleasant pictures, yielded just as little overestimation as the flat color surfaces, whereas neutral pictures were among those judged to arrive latest.

A general content effect could explain part of these results: Pictorial stimuli lead to an overestimation of TTC compared to simple filled colored rectangles. However, since the variability of the TTC judgments (SDs) was not affected by content, whereas means varied systematically, the results cannot be explained by simple distraction from the task. Instead, pictorial stimuli may draw attention to the objects and contours depicted on the picture instead of onto the picture's outer edges. This shift of attention may automatically lead to a reliance on those inner contours for the TTC estimation. Longer TTC estimates for pictorial stimuli than for flat color stimuli would then correspond to a size-arrival effect (DeLucia, 1991).

Assuming such a basic content effect, medium arousal may have cancelled the judgment-prolonging content effect by improving general cognitive functioning, including concentration on the TTC task, following the classical Yerkes-Dodson-Law (Yerkes & Dodson, 1908). Performance at optimum arousal level was comparable to performance with content-free control stimuli. Unpleasant arousal may have had this beneficial effect even at higher arousal levels, in line with the ecologically reframed Yerkes-Dodson Law: "[…] when high emotional arousal states correspond to the type of performance required, performance does not need to deteriorate." (Hanoch & Vitouch, 2004, p. 444)

Hanoch and Vitouch (2004) – among others – argue convincingly that classifying emotions into the two dimensions of arousal and valence does not do them justice. Instead each emotion is a mechanism evolutionarily shaped to solve specific problems and will thus have specific effects depending on task and context. Even though we did not use separate categories for several distinct emotions in this experiment, our unpleasant arousing stimuli (threatening or repulsive) do fit better to the task than our pleasant arousing ones: Usually, it is unnecessary to estimate the exact arrival time of approaching pleasant stimuli. It would not have been evolutionarily beneficial, however, if an approaching aversive object resulted in overly delayed estimates of its collision. Nevertheless, a study investigating the effects of

several distinct unpleasant emotions on TTC estimation, such as fear, sadness and disgust, would be useful to explore those possible categorical differences.

8.3.6   General discussion

We set out to examine which specific aspect of the emotional content of a looming stimulus was responsible for the threat advantage effect found in earlier TTC studies (Brendel et al., 2012; Vagnoni et al., 2012). In Experiment 9 threatening pictures were not judged to arrive earlier than highly arousing pleasant pictures, which would speak for an arousal effect. Experiment 10 replicated such an effect for threatening pictures in a group of spider fearfuls and showed that it generalizes to pictures of the feared object. Unexpectedly however, a threat advantage effect was absent in the control group and prolonged TTC estimates were observed for spider pictures in this group. TTC estimates did not correlate with subjective arousal ratings (Experiment 9 and 10), but we observed a negative correlation between objective measures of arousal (skin conductance responses) and TTC estimates in Experiment 10. Finally, Experiment 11 showed that the highest arousing pleasant pictures did not produce a pleasure advantage effect in addition to the threat advantage effect but led to longer TTC judgments (equal to neutral pictures). In contrast, the highest arousing threatening and repulsive pictures led to the known threat advantage effect of shorter judgments compared to neutral pictures.

Threat advantage, however, seems to be an oversimplification since the same effect was observed with both pleasant and unpleasant pictures if those induced medium arousal, and even with flat color surfaces. All those lead to a reduced overestimation of TTC compared to neutral, low arousing, and pleasant high arousing pictures. Thus, neither arousal nor threat alone can explain the effect. The main issue seems to be a general content effect. In general, pictorial stimuli appear to prolong TTC estimates. This effect, however, seems to be reduced by medium or task-corresponding (in our case: aversive) arousal – a notion fitting the ecologically reframed Yerkes-Dodson Law (Hanoch & Vitouch, 2004; see discussion of Experiment 11).

In addition to this arousal-modulated content effect, specific fear such as fear of spiders – or rather the absence of such fear – can alter the pattern of results (Experiment 10): Whereas the response pattern in the group of spider fearfuls – shorter TTC estimates for generally threatening (attack) and specific aversive stimuli (spiders) compared to neutral or pleasant pictures – is comparable to the results of the other experiments, the data of the control group seems to be incompatible with the current findings

as well as the previous literature (Brendel et al., 2012; Vagnoni et al., 2012). The observed larger TTC estimates for spider pictures in this group might result from a size-arrival-effect (DeLucia, 1991) as discussed above. The absence of a shortening of TTC judgments for generally threatening stimuli is more difficult to reconcile. Though fear of spiders and trait anxiety are not necessarily correlated (Davey, 1991), modulations of the processing of emotional stimuli by fearfulness and trait anxiety may be a related phenomenon (Tipples, 2011). Such modulations have been shown in various perception tasks (Bar-Haim, Kerem, Lamy, & Zakay, 2010; Buetti & Lleras, 2012; Byrne & Eysenck, 1995; Ferneyhough, Kim, Phelps, & Carrasco, 2013). Future studies will have to reveal to what degree such personality factors have an impact on TTC estimates of emotional material.

Taken together, it seems that a cognitive evaluation of the emotional stimulus has to occur for the modulation of the content effect to arise – which would be in line with our previous finding (Brendel et al., 2012) that the emotional effect on TTC estimates does not surface with a very short presentation time (200 ms) – and this cognitive evaluation underlies the difference between the fearful and non-fearful participant's behavior.

8.3.6.1 Mechanism

Earlier (Brendel et al., 2012), we proposed an acceleration of the biological clock by physiologically arousing stimuli (Dirnberger et al., 2012; Gil & Droit-Volet, 2011) as the mechanism behind the emotional effect on TTC estimates: A clocking process is needed in the prediction-motion paradigm to count out the estimated TTC (Tresilian, 1995), and arousing pictures can have an effect on time perception subsequent to stimulus presentation (Shi, Jia, & Müller, 2012). Thus, a quicker accumulation of timing pulses during the post-perceptual cognitive motion extrapolation would have been an explanation – if shortened judgments had *always* been induced when physiological arousal was high. However, while correlations with SCRs in Experiment 10 would back this notion, the finding of a reduced emotional modulation of TTC estimates in the control group of Experiment 10 speaks against it.

Interestingly, we did not observe changes in the variability of TTC estimates as a function of emotional factors. Thus, the current effects do not seem to reflect an emotionally induced undirected distraction from the task. Instead, the data of the experiments described here need to be explained by a *directed* distraction. The visual system probably relies on looming detectors, that is, on neurons that detect an approaching object by detecting edges in the retinal image which are symmetrically moving in

opposite directions (Münch et al., 2009) or even on tau neurons calculating an object's arrival time from those diverging edges (Lee, 1976). Since most approaching objects in the real world do provide a variety of edges and surfaces, a decision must be made on which of those edge pairs to rely for estimating TTC. In the case of TTC estimation with threatening stimuli, the often reported negativity-bias in the processing of emotional pictures (e.g. Olofsson et al., 2008) may be due to a reliance on primarily those looming detectors that signal the earliest TTC (see Rushton & Wann, 1999). This makes sense in the real world: Judging the TTC of the knife in an attacker's hand makes more sense than judging TTC of the attacker's body contours. The case is different with pictorial stimuli: In principle, all computations of tau based on the edges of an object depicted on a picture would result in the TTC of the picture itself. However, since TTC estimates of human observers are influenced by the size of the approaching object, the estimate based on inner contours instead of outer edges would lead to longer TTC judgments.

Of course, this explanation of the encountered effects is highly speculative. In most pictures used here, it would be hard to determine the precise depicted size of the objects or the very edges that might have been used for estimating TTC. A study using simple geometrical shapes would be useful to examine how visual bottom-up and cognitive top-down mechanisms choose those features of a looming stimulus to be used for TTC estimation.

There is a possibility that physical attributes of our picture categories like color, complexity, spatial frequency or composition may have influenced the results we ascribed to the factors arousal, valence, or specific fear (see Olofsson et al., 2008, Section "5.2.4. Physical stimulus attributes"). However, such an influence of physical attributes is unlikely, since we found consistent effects with in part considerably different picture samples in our three experiments.

8.3.7   Conclusion

This study adds to the growing literature that shows affective influences on visual perception, mainly based on arousal and individual traits such as fearfulness or anxiety. We intended to answer the question of whether arousal or threat was responsible for shorter TTC estimates of approaching threatening pictures compared to neutral ones. Our results suggest first of all a general content effect at work: If participants are to judge when a looming picture will arrive at their position, they will overestimate the arrival time. We propose a directed, probably attentional mechanism of picking the wrong edges, that is, picking the depicted content's edges instead of the picture's outer edges as information source for the

judgment. The resulting judged arrival times are delayed due to the smaller visual angle of the chosen edges following the size arrival effect (DeLucia, 1991).

Emotional pictures modulate this content effect, following the ecologically reframed Yerkes-Dodson Law (Hanoch & Vitouch, 2004): Performance is improved – and arrival times are less overestimated – when the pictures induce medium or task-relevant high (in our case: aversive) arousal. Fearfulness, in turn, alters this modulating effect of arousal: Specific fears (fear of spiders) lead to a stronger threat advantage effect whereas the judgments of non-fearful participants are less affected by arousal. Carefully designed studies are needed to examine the mechanism of the content effect in TTC estimation, especially regarding the roles of visual bottom-up and cognitive top-down processes.

9   PART II: SAFETY STRATEGIES AND IMPAIRED VISUAL CONDITIONS[10]

9.1   Abstract

Driving with impaired vision or in situations of reduced visibility is associated with an increased risk of accidents. Aside from obvious factors, such as the slipperiness of snow-covered ground and longer reaction times for barely visible obstacles, less obvious or unnoticed changes of the stimulus may likewise reduce the ability to correctly time impending collision events. We measured the potential effects of commonly occurring changes in contrast, dioptric blur, and simulated snowfall on basic time-to-contact estimation. A simple object approached the observers at constant speed and was occluded after one second. The observers had to press a button when they thought the object would have collided with them (prediction motion paradigm). We found that reduced stimulus contrast lengthened time-to-contact estimates, whereas dioptric blur and snowfall shortened them, all without changing the estimations' uncertainty. We consider a slower perceived speed the most probable explanation for the effect of reduced contrast. The effects of dioptric blur and snowfall could be explained by an implicit safety strategy of the visual system, which introduces a behaviorally safe bias.

9.2   Introduction

Of the variety of well known risk factors for car accidents like inappropriate speed, alcohol use and driver fatigue, some are especially related to the degradation of the visual stimulus. Stimulus degradations can be induced by two different venues. Firstly, the stimulus itself can be obscured by changes in lighting, fog, rain, and other environmental factors. Secondly, the perception of the stimulus can be compromised by the state of the observer, be it for systemic (fatigue, inebriation) or for front-end reasons (cataracts, reduced visual acuity, etc.).

Precipitation is associated with large increases in traffic collisions and injuries (Mills, Andrey, & Hambly, 2011) and driving with impaired vision is associated with an increased risk of at-fault crashes (Owsley, Stalvey, Wells, Sloane, & McGwin, 2001). Besides the obvious effects of precipitation and

---

[10] Manuscript in preparation: Brendel, E., Sicorello, M., Hörichs, J., Kiltz, L., & Hecht, H. (in preparation). Time-to-collision estimation under impaired visual conditions.

impaired vision - like a slippery ground or not detecting an obstacle in time - more subtle effects of such conditions on visual perception may also be at work. We conducted two experiments to investigate the effects of certain visual impairments on a basic perceptual function that is thought to play an important role in the visual control of driving. Specifically, we examined the effects of environmental (motion signals in the periphery like with snowfall, contrast reduction like with fog) and observer-related (contrast reduction like with cataract, blurred vision like with cataract and myopia) stimulus degradation on observer-collision time-to-contact (TTC) estimation.

9.2.1   TTC in driving

Since Lee (1976) proposed his model of TTC estimation as the potential perceptional control system for driver's braking decisions it has become a key metric in traffic safety (e.g. Hugh, Charlton, & Perrone, 2008; van der Horst, 1990; van Winsum & Heino, 1996). There are studies challenging the view that TTC is a critical perceptual variable in this context. In a study of individual TTC estimation and collision detection ability DeLucia, Bleckley, Meyer, and Bush (2003) found that only the latter was correlated with actual accident history, and this correlation was only found in younger drivers. However, in this study observers had to estimate TTC of two objects colliding with each other, a task that is less relevant for driving safety than TTC estimation of looming objects, that is, objects moving on a collision course with the observer. Those two tasks, estimating the TTC of two frontoparallely moving objects versus estimating TTC of a looming object, are thought to involve different mechanisms (Calabro, Beardsley, & Vaina, 2011).

Several studies support the notion that TTC estimation of looming objects plays a critical role in traffic safety. Observing road traffic on a junction for 6 days, Vogel (2003) found that TTC is more variable depending on different measurement sites than headway and concludes that TTC might be the best measure for safety in actual traffic conflicts. In a driving simulator study, Hugh et al. (2008) found that drivers initiate braking at a constant TTC to a decelerating preceding vehicle. The value of this braking-point-TTC depends on factors like vehicle speed, lead vehicle size, and driver distraction. Likewise, van Winsum and Heino (1996) reported that TTC affects the initiation and control of braking. In contrast, the rate of optic expansion showed no systematic pattern at the point of breaking in Hugh et al.'s study. Note that TTC can be thought of as the inverse of the relative rate of expansion. The simpler parameter of mere optical expansion, is a looming signal that may be involved in the automatic

redirection of attention and cognitive resources in the case of imminent collisions (Hugh et al., 2008) and thus may be more closely related to the collision detection ability tested by DeLucia, Bleckley et al. (2003), as compared to TTC.

Real driving tasks and driving simulations invoke a specific observer mindset which could affect their ability to deliver basic perceptual estimates. Driving experience and other types of biases can influence actual driving behavior under stimulus degradation, and thus could probably also influence TTC estimation under the same conditions. For example, young experienced drivers make greater adjustments of their driving speed in response to fog than young novice drivers (Mueller & Trick, 2012). Another example is that at high driving speed, fog separates drivers into two distinct groups, one increases their car following distance beyond the visible limit, while the other keeps following the lead car within the shortened visual range in spite of this following distance being too short for an emergency break (Broughton, Kathy L M, Switzer, & Scott, 2007). To avoid such behavioral biases influencing our measurements, we decided to test TTC estimation without the implications of a driving situation and used basic visual stimuli and a simple response button instead.

9.2.2   Reduced contrast and blurry vision

One example for observer-related stimulus degradation is cataract. Among the most common symptoms of cataract are cloudy or blurry vision or the phenomenon that colors seem faded (National Eye Institute, 2015). Contrast is also reduced by fog, in which case it is an environmental stimulus degradation. Due to the 'symptomatic' similarity of reduced contrast, we will review how fog and cataract affect performance in several driving and perception tasks together in one section.

Impairments in visual acuity and contrast sensitivity are associated with self-reported driving difficulty (McGwin, Chapman, & Owsley, 2000). The visibility of a target is an important factor limiting the reaction time for any action a driver could take to avoid a crash (Halmaoui, Hautière, Joulan, Brémond, & Cord, 2015). Dense fog obscures the outline of a leading vehicle, which causes longer reaction times in a task where the following driver has to decide whether the distance to the lead car is getting shorter or longer (Caro, Cavallo, Marendaz, Boer, & Vienne, 2009). This finding may be related to effects of reduced contrast on speed perception. Foggier scenes are perceived to be moving more slowly and drivers in a simulator drove faster in foggy scenes to match a given target speed (Snowden, Stimpson, & Ruddle, 1998). Horswill and Plooy (2008) found that reducing contrast in a video-based

driving simulator made speeds not only appear slower but also harder to discriminate. Drivers also show greater matching speed errors in a car-following task when dense fog is added to the scenery (Ni, Kang, & Andersen, 2010).

In addition to reaction time and speed perception, more complex visual functions are also affected by adverse visual conditions. Ni, Bian, Guindon, and Andersen (2012) found a decreased collision detection sensitivity (but no change in bias) with simulated fog for older but not for younger observers. When they measured collision detection performance while simulating observer motion, they found a changed response bias towards the detection of a collision event but no main effect of fog on collision detection sensitivity in either group. However, their longest TTC (6 s) combined with their slowest observer motion speed (20 km/h) also resulted in lowered collision detection sensitivity in the presence of fog.

In a real-world driving situation, low light conditions impaired the recognition of objects along the way (Wood & Owens, 2005). This performance impairment was more strongly predicted by the observers' contrast sensitivity than their visual acuity measured under standard photopic conditions. Visual acuity measured under low-luminance conditions, however, was highly correlated with contrast sensitivity.

(Owsley et al., 2001) found that older drivers with cataracts and a history of an at-fault vehicle crash during the 5 years preceding the study, were significantly more likely to have a serious contrast sensitivity deficit. Looking into the causality of this relationship, Marrington, Horswill, and Wood (2008) simulated moderate cataract with special spectacles (keeping vision still within legal driving limits) and found, that participants, who wore those spectacles, were slower to detect and anticipate traffic hazards.

Contrast reduction seems to be the most critical common factor for driving in fog, in low-light conditions or with cataract. To our knowledge, no study has investigated its effects on TTC estimation yet. In Experiment 12 we examine the basic perceptual effect of contrast reduction on TTC estimation, combined with blurry vision, to additionally cover this aspect of cataract or myopia.

9.2.3 Snowfall

In a trend-analysis of Canadian weather and collision data between 1984 and 2002, Andrey (2010) found that relative risk of casualty during rainfall had dropped from 90% to 50% above normal driving conditions – possibly due to awareness and Advanced Driving Assistance Systems (ADAS). In contrast,

the relative risk of casualty during snowfall stayed at a constant 87% above normal. Most of this difference is probably due to the more slippery ground. However, there is another factor that is more prominent for snowfall than for rain: an increase in surrounding motion signals.

The detection of looming is based on two separate mechanisms, one for optic flow and another for scale changes, and neither of these two mechanisms is affected by adaptation of the other (Calabro, Rana, & Vaina, 2011), but both mechanisms play a role in TTC estimation with looming stimuli.

In general, optic flow - especially in the visual periphery - is important in self-motion perception (Kim, 2013), as are central and peripheral looming detectors which produce very similar responses to fast-approaching objects (Stoffregen & Riccio, 1990). In contrast, a motionless textured background seems to have little effect on TTC estimation (Landwehr, 2004). The same is true for expansion signals from small, local image elements as opposed to the global motion pattern of random dot kinematograms (Giachritsis & Harris, 2005; Harris & Giachritsis, 2000). The texture of a more coherently rendered moving object can influence TTC estimates for that object (Oberfeld, Hecht, & Landwehr, 2011; Vincent & Regan, 1997). And the optic flow in the surrounding visual field that signals observer motion can also influence the TTC estimates of an independently approaching object: Estimated TTC of an approaching object decreases with forward self-motion (Geri, Gray, & Grutzmacher, 2010; Gray & Regan, 2000; Hesketh & Godley, 2002) and increases with backward self-motion (Gray & Regan, 2000). A similar influence of surrounding motion signals has even been shown for only one additionally moving object: If a simultaneously approaching distractor arrives later than the approaching target, TTC estimates of the target are shortened (Oberfeld & Hecht, 2008).

Falling snowflakes provide motion signals that do not constitute optic flow (signaling self-motion). Nor do they specify additional objects approaching the observer on a collision course. But the increased motion signals surrounding an approaching object may still affect TTC estimation for that object. They can be thought of as a special case of stimulus degradation.
In Experiment 12, we manipulate the stimulus akin to visual impairment of the observer. In Experiment 13 we manipulate the stimulus akin to an environment-related degradation, such as simulated snowfall.

9.3   Experiment 12: Observer-related stimulus degradation

In this experiment we investigated what effect reduced contrast, blurred vision, and a combination of both have on frontal TTC estimation. Based on the above-mentioned studies we hypothesized that under reduced contrast participants perceive the approach velocity as slower and thus estimate TTC to be longer (constant error). We hypothesized a similar effect for blurred vision. In addition, we hypothesized that these impairments increase the uncertainty of the TTC estimations (variable error).

We also modified the affective content to the stimuli for two reasons. First, the affective content of an approaching stimulus has a small influence on TTC estimation (Brendel et al., 2012; Brendel, Hecht, DeLucia, & Gamer, 2014; DeLucia et al., 2014). By adding emotion as a variable we can compare the effect of the impairment to one of emotion. Second, an arousal- or threat-advantage effect could be particularly strong under impaired visual conditions, if those increase the uncertainty of the impending collision.

9.3.1 Method

9.3.1.1 Participants

24 people participated in the experiment, some for partial course credit (11 men, 13 women; aged 19-36 years, $M = 24.15$, $SD = 4,53$). Most of them were students at the University of Mainz, 13 of them students of psychology, and all had normal or corrected-to-normal visual acuity and contrast sensitivity. All participants were treated according to the Helsinki convention and gave their written informed consent.

9.3.1.2 Apparatus and stimuli

Displays were presented on a projection screen (2.5 m wide x 1.5 m high, Optoma HD20 projector) with a Dell Precision 390 (Intel Core 2 CPU-6400 2,13 GHz 4GB RAM Windows 7 64 Bit, graphics card NVIDIA GeForce GTX 690, resolution 1920 x 1080 pixel) at 24 frames/s in a darkened room. A chin rest stabilized head position at a 2 m viewing distance. The stimuli were programmed in virtual space (Vizard 3.0); one virtual m corresponding to one real m.

Nine images from the International Affective Picture System (IAPS, Lang et al., 2005) served as stimuli. They represented three affective categories and were chosen from images we had used in our earlier experiments (Brendel et al., 2012; Brendel et al., 2014): The attack category consisted of a snarling Pit Bull, a masked attacker with a knife, and a biting snake, associated with high arousal and low valence ratings. The erotic images were chosen with high arousal and high valence ratings. Finally, for the neutral

category three images showing a man with a hat, a lamp, and plants, respectively, were associated with

low arousal ratings and intermediate to high valence ratings[11]. Images of the three categories covered the

same range of contrast, depth impression, and spatial frequency. As control condition we created three

noise images colored black-white, black-red and black-blue (Figure 13).
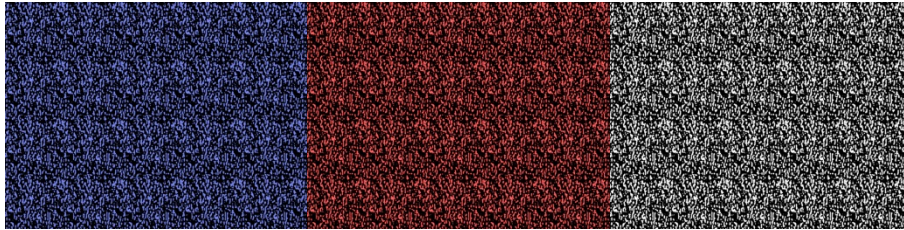
Figure 13.   Stimuli for the "noise" control condition in Experiment 12.

9.3.1.3   Simulated visual impairments

In the reduced contrast condition, we placed a virtual semi-transparent white mask with 15 %

transparency in front of the stimulus, which reduced stimulus contrast and made the virtual environment

appear as if seen through cataracts or fogged-up glasses. Furthermore, participants wore an optometrist's

trial frame, into which lenses of different dioptric values were inserted. For the dioptric blur condition, we

used lenses with +1.5 and +3 diopters, which resulted in a mild to moderate blur of vision, respectively.

Those lenses are equivalent to an uncorrected myopia of 1 and 2.5 diopters, respectively (since 0.5

diopters of accommodation are needed for clear vision at the viewing distance of 2 m). Lenses with

0 diopters served as control condition. For a detailed description of the simulated visual impairments see

(Hecht, Hörichs, Sheldon, Quint, & Bowers, 2015, pp. 2401–2402). This experiment was part of an effort

to assess the effects of combinations of reduced contrast and dioptric blur conditions on various visual

tasks. Visual acuity was measured using the Landolt C set of the Freiburg Acuity Test (FrACT,

http://michaelbach.de/fract/index.html; Bach, 1996, 2006). Contrast sensitivity was measured using a

custom test based on the Pelli-Robson chart (Pelli, Robson, & Wilkins, 1988). Here, we report the tests

conducted at 4 m viewing distance, which, needing 0.25 diopters accommodation, is still comparable to

this experiment's viewing conditions, while avoiding to run into the limits of display resolution. Dioptric

blur caused a marked and almost linear reduction in visual acuity and contrast sensitivity. The

---

[11] The IAPS numbers of the pictures used were: 1120, 1300, 2190, 4311, 4659, 4695, 5000, 6510, 7175.

semitransparent mask further reduced contrast sensitivity in all three dioptric blur conditions and visual acuity at 0 and -1.5 dioptric blur (for details see Hecht et al., 2015, pp. 2401–2402).

9.3.1.4 Design and procedure

In a prediction-motion paradigm an image (2 m width x 1.5 m height) was depicted to approach the participant through a tunnel at constant velocity for 1 s, and then was blanked out. Participants had to extrapolate the motion of the picture after it disappeared and to press a button when it would have collided with them. TTC estimates were calculated as the time from the pictures' disappearance to the participant's button press. To discourage participants from basing their judgments on simple heuristics, we varied approach velocity and actual TTC (time from disappearance to collision). We chose TTC values below 1.5 s as they are relevant in the perception of critical traffic encounters (van der Horst, 1990).

The repeated-measures design consisted of five fully crossed factors: *picture category* (4 levels: attack, erotic, neutral, noise), *velocity* (2 levels: 4 and 5 m/s), *TTC* (3 levels: 0.8, 1.0, and 1.2 s), *contrast* (2 levels: 100 % transparency and 15 % transparency), and *diopter value* (3 levels: 0, +1.5, and +3.0 diopters). Altogether, participants viewed 432 trials (12 pictures x 2 velocities x 3 TTCs x 2 contrast conditions x 3 diopter values), starting each trial at their own pace. The three diopter-values and the two contrast conditions were blocked; the order of the resulting six blocks was counterbalanced according to the method of latin squares. The order of the trials within each block was randomized. Six training trials with feedback (a prompt of the estimation error in ms and whether the button press occurred too early or too late) preceded the experiment, each without contrast reduction or dioptric blur, and with a photograph that was not used as an experimental stimulus.

After all TTC judgments had been made, we assessed arousal and valence ratings for the stimuli in the same manner as these values were assessed for the IAPS catalogue: We showed each picture again for 6 s, asking the participants: "How do you feel when you look at this picture?". The ratings were collected with self-assessment-manikins (SAMs, Lang, 1980), a scale consisting of five sketches depicting the affective states. Participants can choose one of the manikins or an intermediate state, resulting in a 9-point scale.

9.3.2   Results

9.3.2.1   Constant error (mean)

We computed TTC estimation errors (estimated TTC – actual TTC), averaged across the three trials per factor-combination and analyzed those averages in a 4 (picture category) x 2 (velocity) x 3 (TTC) x 2 (contrast) x 3 (dioptre value) ANOVA with repeated measures on all factors. For all data analyses described in this paper we used SPSS 21, for all ANOVAs we used an alpha level of 5% and report Huynh-Feldt corrections where utilized. Figure 14 shows all statistically significant effects and interactions.

TTC was overestimated in normal viewing. Reduced contrast led to a *greater overestimation* of TTC, $F(1, 23) = 7.21$, $p = .01$, $\eta_p^2 = .24$, but adding dioptric blur *shortened* the TTC estimates, $F(2, 46) = 4.09$, $p = .02$, $\eta_p^2 = .15$. The effect of dioptric blur was further investigated by two planned contrasts at a Bonferroni corrected alpha of 2.5%, revealing that the TTC estimates at 0 diopters were longer than the pooled estimates of +1.5 and +3.0 diopters, $F(1, 23) = 7.57$, $p = .01$, $\eta_p^2 = .25$, and that the estimates at +1.5 diopters did not differ significantly from those at +3.0 diopters, $F < 1$.

TTC was also estimated longer, when the images approached faster, $F(1, 23) = 85.99$, $p < .001$, $\eta_p^2 = .79$. Picture category had a significant effect on TTC estimates, $F(3,69) = 6.88$, $\varepsilon = .79$, $p = .001$, $\eta_p^2 = .23$, a main effect further investigated by three planned contrasts at a Bonferroni corrected alpha of 1.66 %: We compared the average estimated TTC error of each picture category to the noise condition, which was meant to serve as a control. The only significant difference was found for neutral pictures, $F(3,69) = 25.81$, $p < .001$, $\eta_p^2 = .53$, both other $F < .05$, $p > .8$. Approaching neutral images led to a significantly greater overestimation of TTC than images of the noise category, whereas the attack and erotic category made no difference compared to our noise control.

There was no significant main effect of the factor TTC and no significant interaction except one between contrast condition, velocity and TTC: $F(2,46) = 5.54$, $p = .01$, $\eta_p^2 = .19$. Figure 14 (upper right panel) reveals the nature of this threefold-interaction: The effect of reduced contrast at higher approach velocity is more pronounced with longer TTCs, and at lower approach velocity it is more pronounced with shorter TTCs.
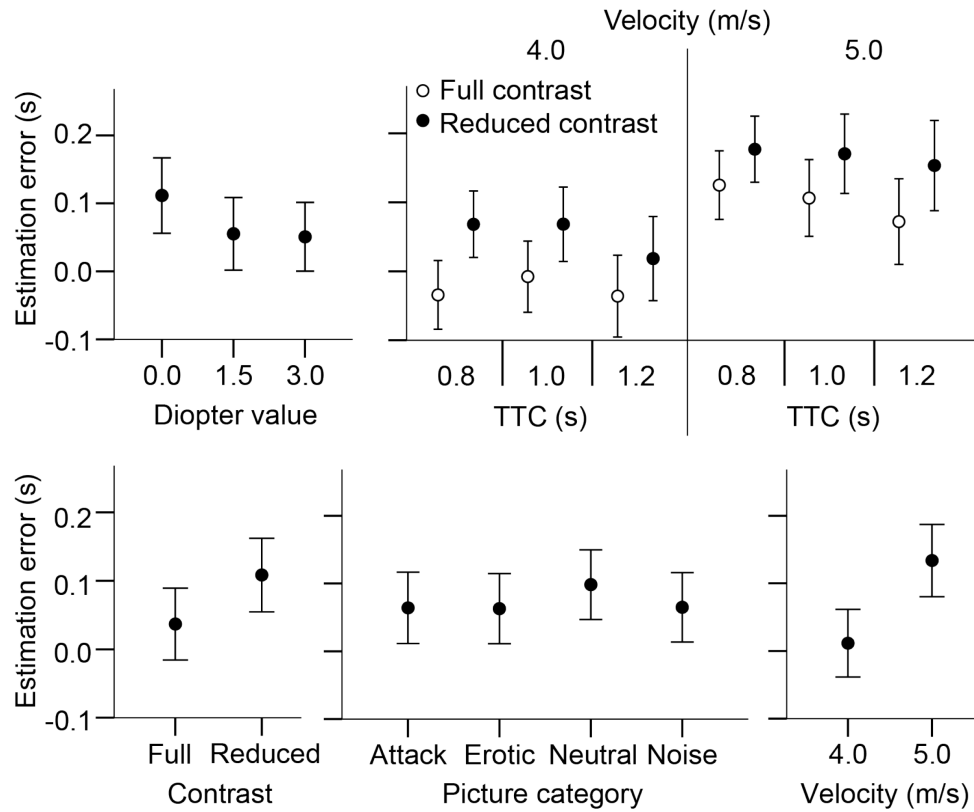
Figure 14. Experiment 12. Average TTC estimation error (estimated TTC - actual TTC) as a function of diopter value (upper left panel), contrast condition (lower left panel), picture category (lower middle panel), velocity (lower right panel), and velocity interacting with TTC and reduced contrast (upper right panel). Error bars represent standard error of the mean across participants.

9.3.2.2   Variable error (SD)

To examine whether the differences of the average TTC estimation errors were accompanied by an increased uncertainty under impaired vision, we analyzed standard deviations of TTC estimation errors. A 4 (picture category) x 2 (velocity) x 3 (TTC) x 2 (contrast) x 3 (diopter value) ANOVA with repeated measures on all factors showed no significant main effect or interaction involving the factor picture category, all $F < 2.4$, $p > .08$. Thus we collapsed across this factor in order to compute standard deviations of TTC estimation errors based on 12 trials per factor combination. We analyzed those standard deviations in a 2 (velocity) x 3 (TTC) x 2 (contrast) x 3 (diopter value) ANOVA with repeated measures on all factors.

TTC had the only significant main effect (see Figure 15), $F(2,46) = 9.35$, $p < .001$, $\eta_p^2 = .29$, which was investigated further at a Bonferroni corrected alpha of 2.5%. 1.2 s TTC led to a significantly greater SD of TTC estimation errors compared to 1.0 s TTC, $F(1,23) = 6.52$, $p = .02$, $\eta_p^2 = .22$, the difference between 0.8 s and 1.0 s TTC did not reach significance, $F(1,23) = 4.78$, $p = .04$, $\eta_p^2 = .17$.

The only significant interactions were between contrast and velocity, $F(1,23) = 10.01$, $p = .004$, $\eta_p^2 = .30$, with reduced contrast increasing estimations uncertainty at the lower velocity only, and between velocity and TTC, $F(2,46) = 3.39$, $p = .04$, $\eta_p^2 = .13$ (see Figure 15).
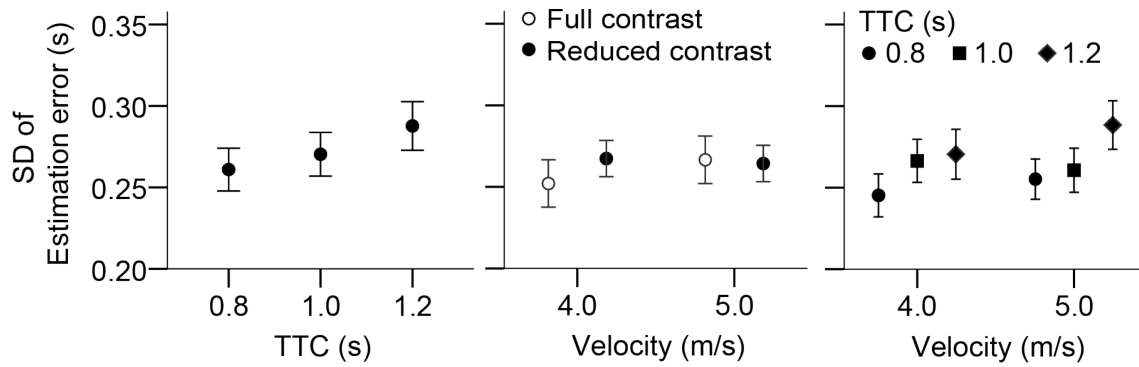
Figure 15. Experiment 12. Average standard deviation (SD) of TTC estimation errors as a function of TTC (left panel), of velocity in interaction with contrast condition (middle panel), and of velocity in interaction with TTC (right panel). Error bars represent standard error of the mean across participants.

Neither contrast nor diopter value, nor their interaction had a significant influence on the standard deviation of TTC estimation errors (all $F < 1$), except for the interaction of reduced contrast with velocity described above. The main effect of velocity was marginally significant, $F(1,23) = 4.01$, $p = .06$, $\eta_p^2 = .15$, all other $F < 1.85$, $p > .13$.

9.3.2.3 SAM ratings

SAM ratings are shown in Figure 16. We calculated mean arousal and valence ratings for each picture category and analyzed those in two separate ANOVAs with picture category as 4-levelled repeated measures factor. The differences between the ratings for each picture category were significant, $F_{arousal}(3,66) = 30.07$, $\varepsilon = .80$, $p < .001$, $\eta_p^2 = .58$; $F_{valence}(3,66) = 53.94$, $\varepsilon = .78$, $p < .001$, $\eta_p^2 = .71$. For both results, we calculated three planned contrasts at a Bonferroni corrected alpha of 1.66 %, each against the noise condition, which was included to serve as a baseline. All ratings were significantly different from those of the noise condition, all $F > 9$, $p \leq .005$. The noise-images received higher arousal ratings and lower valence ratings than the neutral pictures.
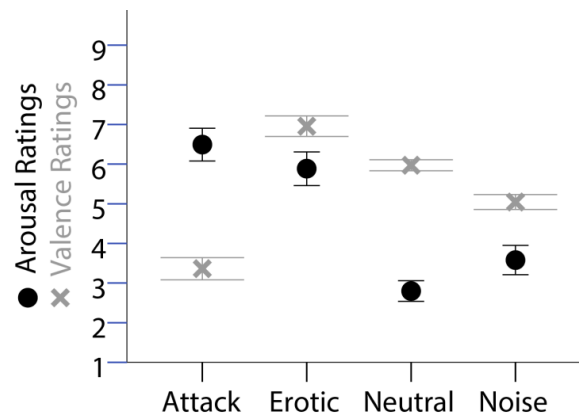
Figure 16. Experiment 12. Average arousal and valence ratings for the categories of images used as approaching objects. Error bars represent standard errors of the mean across participants.

9.3.3 Discussion

As hypothesized, TTC was estimated longer (but not with greater uncertainty) under reduced contrast, which made the contours and texture of the approaching object less crisp. It suggests that the perceived speed might have been slower (Horswill & Plooy, 2008; Snowden et al., 1998). This would be consistent with our manipulation of object speed. Without contrast reduction, TTC was a little overestimated - a finding which is not to be overinterpreted. Many studies involving driving scenarios find TTC underestimation when longer TTCs above 1 s are involved (see van Winsum & Heino, 1996) and overestimation when shorter TTCs are involved. In our earlier research with comparable TTCs we usually found a comparably small TTC overestimation (Brendel et al., 2012; Brendel et al., 2014).

Contrary to our hypothesis, when vision was blurred by +1.5 or +3 diopters, TTC was estimated *shorter* (less overestimation) than when vision was clear. An explanation for this effect might be that participants accelerated their responses because they felt uncomfortable wearing glasses that blurred their vision. They could have attributed the blur to their own state rather than to the object. This could have triggered the use of a simple safety strategy, pressing the button rather too early than too late.

Alternatively dioptric blur might have led to a bigger appearance of the stimuli due to their blurred contour. This could have resulted in a size-arrival-effect (DeLucia, 1991; DeLucia & Warren, 1994), leading to systematically shorter TTC estimates. However, blur circles of 0.02 m and 0.04 m at +1.5 and +3.0 diopters, respectively (diameter approximated as suggested by Thibos & Thibos, 2011), lead to size differences of 2 % to 6 %, depending on diopter value and velocity. These differences were

rather small compared to the size differences typically necessary to demonstrate the size-arrival effect (e.g. 13 % to 22 % in DeLucia & Warren, 1994).

The largest effect was found for velocity. When images approached faster, TTC was estimated longer, in relative terms. Considering that images which approached faster were also depicted smaller at the screen since they always started farther away in the virtual environment (due to the fully-crossed design), the effect is quite plausible and again in accordance with a size-arrival-effect. This strengthens the conclusion that our participants used this simple heuristic.

The affective content of our stimuli also had an effect. TTC for neutral images was estimated longer than TTC for all other conditions. This effect might result from the higher arousal that images of the attack-, the erotic-, and the noise-condition induced (see Figure 16). This would be in accordance with an arousal advantage effect (Brendel et al., 2012; Brendel et al., 2014). Its effect size is comparable to that of reduced contrast. However, this arousal advantage effect did not affect the influence of reduced contrast or dioptric blur on TTC estimation.

The significant interaction between contrast, velocity, and TTC remains unclear. It seems that the effect of reduced contrast was especially pronounced when the combination of TTC and velocity led to the target being especially close to the observer (and visually large) or especially far away (and visually small) at the start of the trial. We are still lacking a good explanation for this pattern.

One limitation of this experiment certainly is that our reduced contrast is not directly comparable to fog, since it remained the same intensity at all distances. Under foggy conditions in the real world, objects more distant are harder to detect than objects closer to the spectator. The visual effect may be more comparable to the reduced contrast caused by cataracts.

9.4 Experiment 13: Environmental stimulus degradation

In this experiment we investigated what effect the task-irrelevant motion signals of simulated snowfall have on frontal TTC estimation. Given that the motion of an additional approaching object shortens TTC estimates (Oberfeld & Hecht, 2008), we expected to find shortened TTC estimates in the presence of snowfall, if the snow is perceived to be a reference object/background for the stimulus. Both a safety strategy as well as a possible systematic effect of increased motion signals in the background could lead

to shortened TTC estimates. Having found no influence of affective stimulus content on the effects of reduced contrast or dioptric blur in Experiment 12, we omitted this additional variable in Experiment 13.

9.4.1 Method

9.4.1.1 Participants

21 students of psychology at the University of Mainz (15 women, 6 men; aged 19-38 years, M = 22.76; SD = 4.85) participated in the experiment for partial course credit. All had normal or corrected-to-normal visual acuity. All participants were treated according to the Helsinki convention and gave their written informed consent.

9.4.1.2 Apparatus and stimuli

The participants sat in a darkened room, a chin rest stabilized head position at 0.5 m viewing distance to the screen (52 x 29.4 cm, resolution 1920 x 1080 pixel). The stimuli were programmed in virtual space (Vizard 3.0), one virtual m corresponding to one real m, and presented with a DELL Precision 380 computer, graphics card nVIDIA Quadro FX3500.

The stimulus was a black sphere of 2 m width, frontally illuminated, in a uniform grey environment. In the snow conditions, moderate snowfall under different wind conditions was simulated using Vizard's snow function. The snow was either falling straight downwards, or it was moderately "blown" towards the observer, away from the observer, or from right to left across the screen.

9.4.1.3 Design and procedure

In a prediction-motion paradigm the sphere was depicted as approaching the participant at constant velocity and was blanked out after 1.5 s. Participants were instructed to extrapolate the motion of the sphere after it disappeared and to press a button when it would have collided with them. TTC estimates were calculated as the time from the sphere's disappearance to the participant's button press. To discourage participants from basing their judgments on simple heuristics, we varied approach velocity and actual TTC (time from disappearance to collision).

The repeated-measures design consisted of three fully crossed factors: snow condition (5 levels: no snow, head wind (blowing frontally towards the viewer), tail wind (blowing away from the viewer towards the sphere), side wind and no wind), velocity (2 levels: 4 and 5 m/s), TTC (3 levels: 1.0, 1.25 or 1.5 s). Because we did not want to create an oddball effect for the no-snow condition, we presented each

factor combination twice for the four variations of the snow conditions (48 trials with snow) but four times for the no-snow condition (24 trials without snow). Thus, participants viewed 72 trials in total in randomized orders, starting each trial at their own pace. The experiment was interrupted for two short breaks to relax. Eight training trials with feedback (a prompt of the estimation error in ms and whether it was too short or too long), preceded the experiment, using the stimulus without snowfall.

9.4.2   Results

9.4.2.1   Constant error (mean)

We computed TTC estimation errors (estimated TTC - actual TTC), averaged across the trials per factor combination and analyzed those averages in a 5 (snow condition) x 2 (velocity) x 3 (TTC) ANOVA with repeated measures on all factors. We used an alpha level of 5% and report Huynh-Feldt corrections where utilized.

Significant effects on mean TTC estimation errors are shown Figure 17. We found a significant difference between the snow conditions, $F(4, 80 = 4.91, p = .001, \eta_p^2 = .197$, allowing further investigation of specific mean differences. We calculated two separate contrasts: Firstly, we compared the pooled means of the four 'snow' conditions to the 'no-snow' condition. Secondly, we compared the effect of head wind against tail wind. Both tests were conducted on a Bonferroni corrected $\alpha = .025$.

Corresponding to our hypothesis, there was a significant shortening of TTC estimates in the pooled snow conditions compared to the condition without snow, $F(1, 20) = 11.95, p = .002, \eta_p^2 = .374]$, but the effect of snow on time-to-contact estimation errors did not differ significantly between tail wind and head wind, $F(1, 20) = 1.87, p = .186, \eta_p^2 = .086)$. On average, TTC was overestimated by 58 ms (SD = 488) without snow, and underestimated by 48 ms (SD = 469) in the presence of virtual snowfall.

TTC was estimated longer, when the object approached faster, $F(1, 20) = 57.85, p < .001,$ $\eta_p^2 = .74$. With increasing actual TTC of the stimulus, the average TTC estimation error changed from overestimation for the shortest actual TTC to underestimation for the longest, $F(2, 40) = 31.75, p < .001,$ $\eta_p^2 = .61$. There was no significant interaction, all $F < 1.73, p > .09$.
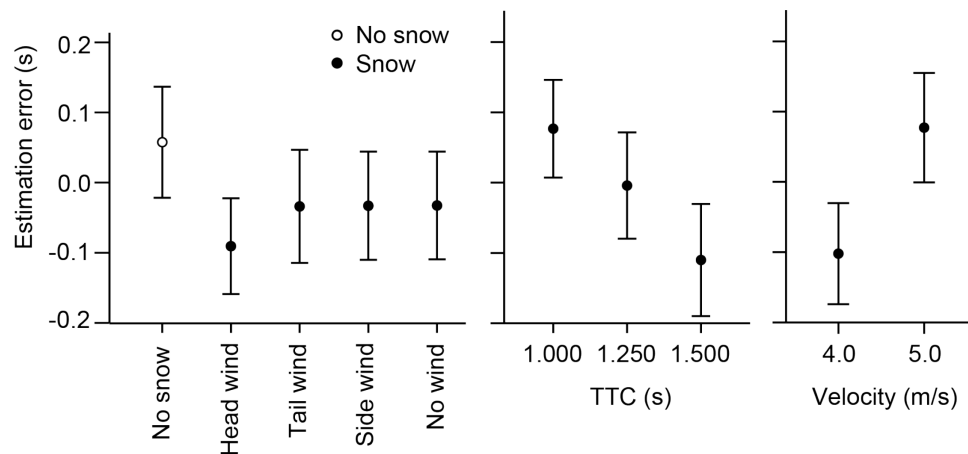
Figure 17. Experiment 13. Mean TTC estimation errors (estimated TTC - actual TTC) as a function of snow condition (left panel), TTC (middle panel), and approach velocity (right panel). Error bars represent standard error of the mean across participants.

9.4.2.2 Variable error (SD)

We analyzed the standard deviations of the TTC estimation errors in a 5 (snow condition) x 2 (velocity) x 3 (TTC) ANOVA with repeated measures on all factors. None of the main effects or interactions reached significance, all $F < 3.30$, $p > .06$. Thus, the uncertainty of TTC estimation was not significantly influenced by any of the factors.

9.4.3 Discussion

Simulated snowfall shortened TTC estimates of a frontally approaching object. This effect was independent of specific wind directions added to the snow. Thus, the additional motion signals in the surround produced a specific effect of underestimating TTC, which cannot be attributed to mere distraction, since the estimates' standard deviation was not increased.

A simple safety strategy should always lead to a shortening in the presence of any additional motion signals, just increasing the safety margin, and is thus the most probable explanation of the results. This does not add TTC estimation to the factors that increase crash risk during snowfall. If the effect had varied with the direction of the snowflakes' motion signals (by means of head wind or tail wind added to the simulated snowfall), a systematic effect of the motion signals would have been be a better explanation.

Based on the lengthening of TTC estimates by the optic flow of backward self-motion (Gray & Regan, 2000), a lengthening of TTC estimates in the case of wind blowing from behind the observer

could have been expected. This would be a perceptual risk-increasing factor. Taking into account that the contrast between the tail wind and head wind conditions was based on considerably fewer trials than the contrast between the no-snow and the pooled snow conditions, the visible trend in the data towards an even greater shortening of TTC estimates with added head wind could actually mean something – and might be statistically detected in an experiment with considerably more trials per condition. At least it should not be ruled out that the systematic effect of optic flow indicating forward self-motion, which has been demonstrated before (Geri et al., 2010; Gray & Regan, 2000; Hesketh & Godley, 2002), was also at work here in the small optic flow components contained in the snow flakes driven by head wind. In addition, the snow was still mainly falling downwards and not blowing straight into the face of the observers. A stronger wind simulation added to the snow thus might also have resulted in a detectable effect of the wind direction. However, such a stimulus would soon become quite close to self-motion optic flow. In a real driving situation, the motion pattern of snowfall would typically contain much more self-motion optic flow.

In conclusion, since we did not find the slightest trend towards a *lengthening* of TTC estimates in the presence of snowfall, not even with added tail wind, a hazardous influence of snowfall on TTC estimation in terms of increasing risky overestimations can be ruled out.

9.5 General discussion

We have compared the effects of observer-related (Experiment 12) and environmental (Experiment 13) stimulus degradations. In Experiment 12, we found that reduced stimulus contrast lengthened TTC estimates of a frontally approaching object and, in contrast, dioptric blur shortened estimates. Both were directed effects; neither reduced contrast nor dioptric blur changed the estimations' uncertainty. We consider the slowing of perceived speed under reduced contrast (Horswill & Plooy, 2008; Snowden et al., 1998) as the most probable explanation of the first finding. This fits to the lowered collision detection sensitivity in the presence of fog found by Ni et al. (2012). Dioptric blur, on the other hand, seems to have triggered a safety strategy. The observers may have adjusted their judgments towards a shorter (and safer) TCC when they noticed the stimulus degradation. This would fit to the assumption of safety strategies at work in the perceptual system, choosing shorter TTCs when various values are available to chose from, and/or adding a safety margin to the output of TTC processors.

In Experiment 13, we found shorter TTC estimates under simulated snowfall, changing from slight overestimation without snow to slight underestimation with falling snowflakes. This again was a directed effect without change in the estimates' uncertainty. We think that a general effect of the additional motion signals surrounding the approaching object is at work here. A stronger head wind simulation might have strengthened the effect, or rather might have added the systematic effect of optic flow from forward self-motion (Geri et al., 2010; Gray & Regan, 2000; Hesketh & Godley, 2002).

The mechanism of the snowfall's effect could be selective integration of the snowflakes' motion signals, or rather of those parts of all available motion signals that determine the shortest TTC, which would be a reasonable safety strategy of the visual system. DeLucia, Kaiser et al. (2003) have shown that different information sources can be combined to form TTC estimates, although such integration does not always happen. For example, it was not found for local image elements and global motion patterns of such artificial stimuli as random dot kinematograms (Giachritsis & Harris, 2005; Harris & Giachritsis, 2000).

It would be interesting to test participants with actual vision impairment (resulting from cataract or glaucoma) to validate the effect of observer-based reduced contrast. There are several studies measuring driving performance of cataract or glaucoma patients (see introduction), but to our knowledge, patient studies with respect to TTC estimation ability wait to be conducted. In addition, it would be interesting to see what effect snowfall has on collision detection, since the possible advantageous effects of the safety strategy that shortens TTC estimates in the presence of snowfall may be cancelled by a decreased collision detection performance.

In conclusion, stimulus degradation has adverse effects on TTC estimation performance. Reduced contrast of the stimulus or fog in the environment lengthened the estimates, thus increasing the risk of accidents. In contrast, dioptric blur and snowfall do not seem to pose this threat. Observers judged these stimuli as if (over)compensating for the degradations they imply. The latter led to perceptual misjudgments, they shortened TTC estimates, which can be interpreted as a perceptual safety strategy.

10 GENERAL DISCUSSION

The purpose of this study was to examine whether there are safety strategies at work in TTC estimation, either in the case of threatening stimulus content or in the case of impaired visual conditions.

10.1 Safety strategies and affective content

Several findings support the notion that TTC estimates are shortened by task-relevant threatening stimulus content. In a prediction-motion-task participants were instructed to extrapolate the motion of a virtually approaching picture after it disappeared and to press a button when it would have collided with them. There was an advantage, that is participants underestimated TTC, when pictures showed frontal attacks compared to approaching neutral images (Experiment 1).

This threat advantage effect seems to rely on some degree of cognitive processing because it surfaced only when participants were given time to process the images' information (Experiment 1). Coarse scrambling of the pictures abolished the effect (Experiment 2). In addition, the frontal attack pictures only had an effect on TTC estimates in a prediction-motion (PM) task, not when relative judgments were made, i.e. when participants had to decide which of two simultaneously approaching pictures would have passed them first (Experiments 7 and 8). This difference also speaks for cognitive involvement (see Tresilian, 1995).

Physiological arousal appears to play an important role in the threat advantage effect. Skin conductance responses (SCRs) recorded during the tasks were negatively correlated with TTC estimation errors while subsequent subjective arousal ratings of the pictures were not (Experiment 10). Thus, it seems that object recognition and some kind of categorization need to have taken place for the picture content to have an effect on TTC judgments, but the effect is not dependent on conscious emotional rating of the content (at least not, if we assume that the self-reported emotional ratings assessed after the experiment were genuine).

Whether it has to be a task-relevant arousal, i.e. whether it is a real *threat*-advantage-effect, depending on a context of physical threat and its avoidance, is less clear. Three findings support the notion that it is. First, the effect seems to be modulated by personal fearfulness. Spider-fearful observers judged both spider pictures and attack pictures to arrive earlier than neutral and pleasant pictures, whereas

a control group with especially low fear of spiders did not show the same pattern of results. However, they did not even show the threat advantage effect in response to frontal attack pictures (Experiment 10). A correlation of individual self-reported fear of specific animals and the shortening of TTC estimates of those animals' approaching pictures was also found by Vagnoni et al. (2012, 2015) and even young infants show earlier defensive blinks in response to looming pictures of snakes and spiders compared to butterflies and rabbits (Ayzenberg, Longo, & Lourenco, 2015). Second, approaching pictures of social threat (aggressive facial expressions) did not elicit the same threat advantage effect as approaching pictures of physical threat (Section 8.2). Third, the threat advantage effect was only detected in the PM task, not when two simultaneously approaching pictures had to be judged (Experiments 7 and 8), which could either be explained by more cognitive involvement in the PM task, but also by the nature of the PM task being more related to the avoidance of physical harm because it involves extrapolating a collision course with oneself and watching a direct looming stimulus instead of comparing the TTC of two objects that are both flying on a miss-path with the observer.

However, there are also findings that contradict a safety strategy of the visual system which specifically shortens TTC estimates of task relevant threatening stimuli. First, in a PM task TTC judgments of frontal attack pictures did not differ significantly from those of erotic, i.e. pleasantly arousing, pictures, when both kinds of pictures were the only ones in the sample (Experiment 9). Secondly, in an experiment using a PM task with a broader sample of pictures, including not only frontal attacks but also repulsive pictures in addition to pleasant and neutral ones, the medium and high-arousing unpleasant pictures and the medium-arousing pleasant pictures all yielded just as little overestimation as the control stimuli (flat color surfaces), whereas neutral pictures were among those judged to arrive latest (Experiment 11, the longest TTC estimates for neutral pictures in a smaller sample of pictures were also found in Experiment 12).

Taken together, the conclusion drawn in the discussion in Section 8.3.6 appears to be the explanation that is most consistent with the results – albeit quite speculative: A general *content effect* seems to be at work in TTC estimation with approaching pictures. By using the depicted content's edges instead of the picture's outer edges as information source for the TTC estimation, the arrival times of pictorial stimuli are overestimated compared to blank squares due to the smaller visual angle of the depicted objects' edges following the size arrival effect (DeLucia, 1991). An *arousal effect* induced by

emotional pictures modulates this content effect, following the ecologically reframed Yerkes-Dodson Law (Hanoch & Vitouch, 2004): Performance is improved – and arrival times are less overestimated – when the pictures induce medium or task-relevant high (in our case: aversive) arousal. Fearfulness, in turn, alters this modulating effect of arousal and leads to a stronger arousal effect whereas the judgments of non-fearful participants are less affected by arousal.

10.2 Safety strategies and impaired visual conditions

If any kind of visual stimulus degradation had always led to shortened TTC estimates, this could have been interpreted as a general safety strategy of the visual system in case of adverse visual conditions. However, not all kinds of vision impairments tested in this study lead to shortened TTC estimates. Reduced stimulus contrast (like with cataract or fog) lengthened TTC estimates of a frontally approaching object (Experiment 12). This was presumably the result of slower perceived speeds under reduced contrast (Horswill & Plooy, 2008; Snowden et al., 1998).

In contrast, dioptric blur (Experiment 12) and simulated snowfall (Experiment 13), shortened TTC estimates. The explanation for both effects may be different, though. Dioptric blur may have triggered a simple safety strategy. The observers may have adjusted their judgments towards a shorter TCC (by just adding a safety margin) when they noticed the stimulus degradation. In the case of simulated snowfall, selective integration of the snowflakes' motion signals, or rather of those parts of all available motion signals that determine the shortest TTC, may have been the cause for the effect. The same mechanism may be the reason for shortened TTC estimates when optic flow indicating forward self-motion is present in the background (Geri et al., 2010; Gray & Regan, 2000; Hesketh & Godley, 2002).

10.3 Conclusion

This study adds to the growing literature that shows how visual perception is influenced by context in its broadest sense, including the visual conditions of a stimulus, the background and surroundings of a perceived object as well as its semantic meaning, and emotional reactions in combination with individual traits of the observer. Safety strategies could be a good explanation for a large part of the results described here, especially for those with affective stimuli, but they are not as specific to threatening stimulus content as hypothesized. In addition, there is not one single kind of safety strategy for TTC estimation in

PM-tasks. Instead, there seem to be specific effects at work for pictorial stimuli, vision impairments and additional motion signals, and some visual conditions tested evoked no safety strategy at all (or it was too weak compared to adverse effects of the stimulus manipulation).

One mechanism was repeatedly thought of as the basis of the shortening of TTC estimates: the selective integration of those parts of all available motion signals that determine the shortest TTC, which would be a reasonable safety strategy of the visual system that has been proposed by others before. Rushton and Wann drew this conclusion after manipulating differing motion signals of one and the same virtual object (Rushton & Wann, 1999). If we assume that there always is a certain amount of defined and functional variability in the TTC processors and their firing thresholds in humans as it has been found in pigeons (Frost, 2010, p. 223) – although motion perception in flying animals is probably more fine-tuned and sophisticated than in grounded animals – this would provide a pool of TTC signals for the visual system to choose from, depending on the circumstances (e.g. attentional focus, optic flow in the background, arousal level).

This explanation is quite plausible, but too general to be of much predictive value. In fact, it predicts nothing specific at all in terms of behavioral output, except that this output may change depending on any kind of factor. What it does specifically predict, however, is the existence of several distinct TTC processors working in parallel and some mechanism for switching their usage depending on context. Current non-invasive neurophysiological measurement techniques like electroencephalography are too coarse to detect possible parallel TTC processing going on before one of those processors becomes the one driving the response of the whole system. I do not support the use of invasive techniques like single-cell-recording on primates for such academic purposes. Instead, maybe some clever perception scientists will succeed in devising a paradigm and experimental design that will be able to answer the question whether such early-stage parallel TTC-processing preceding the percept of (or the reaction based on) a final TTC estimate exists in humans or not.

11 REFERENCES

Alpers, G. W., Adolph, D., & Pauli, P. (2011). Emotional scenes and facial expressions elicit different psychophysiological responses. *International journal of psychophysiology : official journal of the International Organization of Psychophysiology*, *80*(3), 173–181. https://doi.org/10.1016/j.ijpsycho.2011.01.010

Andrey, J. (2010). Long-term trends in weather-related crash risks. *Journal of Transport Geography*, *18*(2), 247–258. https://doi.org/10.1016/j.jtrangeo.2009.05.002

Angrilli, A., Cherubini, P., Pavese, A., & Manfredini, S. (1997). The influence of affective factors on time perception. *Attention, Perception, & Psychophysics*, *59*(6), 972–982. https://doi.org/10.3758/BF03205512

Ayzenberg, V., Longo, M., & Lourenco, S. (2015). Evolutionary-based threat modulates perception of looming visual stimuli in human infants. *Journal of Vision*, *15*(12), 797. https://doi.org/10.1167/15.12.797

Bach, M. (1996). The Freiburg Visual Acuity Test: Automatic measurement of visual acuity. *Optometry and Vision Science*, *73*(1), 49–53. https://doi.org/10.1097/00006324-199601000-00008

Bach, M. (2006). The Freiburg Visual Acuity Test - Variability unchanged by post-hoc re-analysis. *Graefe's archive for clinical and experimental ophthalmology = Albrecht von Graefes Archiv für klinische und experimentelle Ophthalmologie*, *245*(7), 965–971. https://doi.org/10.1007/s00417-006-0474-4

Ball, W., & Tronick, E. (1971). Infant responses to impending collision: optical and real. *Science*, *171*(3973), 818–820. https://doi.org/10.1126/science.171.3973.818

Bar-Haim, Y., Kerem, A., Lamy, D., & Zakay, D. (2010). When time slows down: The influence of threat on time perception in anxiety. *Cognition & Emotion*, *24*(2), 255–263. https://doi.org/10.1080/02699930903387603

Barrett, L. F., Mesquita, B., & Gendron, M. (2011). Context in emotion perception. *Current Directions in Psychological Science*, *20*(5), 286–290. https://doi.org/10.1177/0963721411422522

Baurès, R., Oberfeld, D., & Hecht, H. (2010). Judging the contact-times of multiple objects: Evidence for asymmetric interference. *Acta Psychologica*, *134*(3), 363–371. https://doi.org/10.1016/j.actpsy.2010.03.009

Becker, D. V., Kenrick, D., Neuberg, S., Blackwell, K. C., & Smith, D. (2007). The confounded nature of angry men and happy women. *Journal of Personality and Social Psychology*, *92*(2), 179–190. https://doi.org/10.1037/0022-3514.92.2.179

Bennett, A. G., & Rabbetts, R. B. (1998). *Clinical Visual Optics* (3rd ed.). Oxford: Elsevier Limited; Butterworth-Heinemann. Retrieved from http://www.gbv.de/dms/hbz/toc/ht009001653.pdf

Billington, J., Wilkie, R. M., Field, D. T., & Wann, J. P. (2011). Neural processing of imminent collision in humans. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1711), 1476–1481. https://doi.org/10.1098/rspb.2010.1895

Blanchette, I. (2006). Snakes, spiders, guns, and syringes: How specific are evolutionary constraints on the detection of threatening stimuli? *Quarterly Journal of Experimental Psychology*, *59*(8), 1484–1504. https://doi.org/10.1080/02724980543000204

Bradley, M. M., Greenwald, M. K., Petry, M. C., & Lang, P. J. (1992). Remembering pictures: pleasure and arousal in memory. *Journal of experimental psychology. Learning, memory, and cognition*, *18*(2), 379–390.

Brendel, E., DeLucia, P. R., Hecht, H., Stacy, R., & Larsen, J. (2012). Threatening pictures induce shortened time-to-contact estimates. *Attention, Perception, & Psychophysics*, *74*(5), 979–987. https://doi.org/10.3758/s13414-012-0285-0

Brendel, E., & Hecht, H. (2013, August). *Emotional factors in time-to-contact estimation*. Poster presented at the 36th European Conference on Visual Perception (25-29 August 2013), Bremen.

Brendel, E., Hecht, H., DeLucia, P. R., & Gamer, M. (2014). Emotional effects on time-to-contact judgments: arousal, threat, and fear of spiders modulate the effect of pictorial content. *Experimental Brain Research*, 1–11. https://doi.org/10.1007/s00221-014-3930-0

Brendel, E., Hecht, H., DeLucia, P. R., & Gamer, M. (2014). Emotional effects on time-to-contact judgments: Arousal, threat, and fear of spiders modulate the effect of pictorial content. *Experimental Brain Research.* Advance online publication. https://doi.org/10.1007/s00221-014-3930-0

Brendel, E., Sicorello, M., Hörichs, J., Kiltz, L., & Hecht, H. (in preparation). Time-to-collision estimation under impaired visual conditions.

Brosch, T., & Sharma, D. (2005). The role of fear-relevant stimuli in visual search: A comparison of phylogenetic and ontogenetic stimuli. *Emotion*, *5*(3), 360–364. https://doi.org/10.1037/1528-3542.5.3.360

Broughton, Kathy L M, Switzer, F., & Scott, D. (2007). Car following decisions under three visibility conditions and two speeds tested with a driving simulator. *Accident; analysis and prevention*, *39*(1), 106–116. https://doi.org/10.1016/j.aap.2006.06.009

Buetti, S., & Lleras, A. (2012). Perceiving control over aversive and fearful events can alter how we experience those events: an investigation of time perception in spider-fearful individuals. *Frontiers in psychology*, *3*, 337. https://doi.org/10.3389/fpsyg.2012.00337

Byrne, A., & Eysenck, M. W. (1995). Trait anxiety, anxious mood, and threat detection. *Cognition & Emotion*, *9*(6), 549–562. https://doi.org/10.1080/02699939508408982

Caird, J. K., & Hancock, P. A. (1994). The perception of arrival time for different oncoming vehicles at an intersection. *Ecological Psychology*, *6*(2), 83–109. https://doi.org/10.1207/s15326969eco0602_1

Calabro, F. J., Beardsley, S. A., & Vaina, L. M. (2011). Different motion cues are used to estimate time-to-arrival for frontoparallel and looming trajectories. *Vision research*, *51*(23-24), 2378–2385. https://doi.org/10.1016/j.visres.2011.09.016

Calabro, F. J., Rana, K. D., & Vaina, L. M. (2011). Two mechanisms for optic flow and scale change processing of looming. *Journal of Vision*, *11*(3). https://doi.org/10.1167/11.3.5

Caro, S., Cavallo, V., Marendaz, C., Boer, E. R., & Vienne, F. (2009). Can headway reduction in fog be explained by impaired perception of relative motion? *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *51*(3), 378–392. https://doi.org/10.1177/0018720809339621

Coull, J. T., Vidal, F., Goulon, C., Nazarian, B., & Craig, C. (2010). Using time-to-contact information to assess potential collision modulates both visual and temporal prediction networks. *Frontiers in Human Neuroscience*, *4*(0), 1–12. https://doi.org/10.3389/neuro.09.010.2008

Crawford, L. E., & Cacioppo, J. T. (2002). Learning where to look for danger: Integrating affective and spatial information. *Psychological Science*, *13*(5), 449–453. https://doi.org/10.1111/1467-9280.00479

Davey, G. C. L. (1991). Characteristics of individuals with fear of spiders. *Anxiety Research*, *4*(4), 299–314. https://doi.org/10.1080/08917779208248798

Dawson, M. E., Schell, A. M., & Filion, D. L. (2007). The electrodermal system. In J.T. Cacioppo, L.G. Tassinary, & G. Berntson (Eds.), *Handbook of Psychophysiology* (pp. 159–181). Cambridge University Press.

Dean, P., Redgrave, P., & Westby, G. W. M. (1989). Event or emergency? Two response systems in the mammalian superior colliculus. *Trends in Neurosciences*, *12*(4), 137–147. https://doi.org/10.1016/0166-2236(89)90052-0

DeLucia, P. R. (1991). Pictorial and motion-based information for depth perception. *Journal of Experimental Psychology: Human Perception and Performance*, *17*(3), 738–748. https://doi.org/10.1037/0096-1523.17.3.738

DeLucia, P. R. (2004a). Multiple sources of information influence time-to-contact judgments: Do heuristics accommodate limits in sensory and cognitive processes? In H. Hecht & G. J. P. Savelsbergh (Eds.), *Advances in Psychology: Vol. 135. Time-to-contact* (pp. 243–286). Amsterdam: Elsevier.

DeLucia, P. R. (2004b). Time-to-contact judgments of an approaching object that is partially concealed by an occluder. *Journal of Experimental Psychology: Human Perception and Performance*, *30*(2), 287–304. Retrieved from http://content.apa.org/journals/xhp/30/2/287

DeLucia, P. R. (2005). Does binocular disparity or familiar size information override effects of relative size on judgements of time to contact? *The Quarterly Journal of Experimental Psychology Section A Human Experimental Psychology*, *58*(5), 865–886. https://doi.org/10.1080/02724980443000377

DeLucia, P. R., Bleckley, M. K., Meyer, L. E., & Bush, J. M. (2003). Judgments about collision in younger and older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *6*(1), 63–80. https://doi.org/10.1016/S1369-8478(02)00047-5

DeLucia, P. R., Brendel, E., Hecht, H., Stacy, R. L., & Larsen, J. T. (2014). Threatening scenes but not threatening faces shorten time-to-contact estimates. *Attention, Perception, & Psychophysics.* Advance online publication. https://doi.org/10.3758/s13414-014-0681-8

DeLucia, P. R., Kaiser, M. K., Bush, J. M., Meyer, L. E., & Sweet, B. (2003). Information integration in judgements of time to contact. *The Quarterly Journal of Experimental Psychology Section A Human Experimental Psychology*, *56*(7), 1165–1189. https://doi.org/10.1080/02724980343000053

DeLucia, P. R., & Liddell, G. W. (1998). Cognitive motion extrapolation and cognitive clocking in prediction motion task. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(3), 901–914. https://doi.org/10.1037/0096-1523.24.3.901

DeLucia, P. R., & Meyer, L. E. (1999). Judgements about the time to contact between two objects during simulated self-motion. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1813–1833.

DeLucia, P. R., & Novak, J. B. (1997). Judgments of relative time-to-contact of more than two approaching objects: toward a method. *Perception and Psychophysics*, *59*(6), 913–928.

DeLucia, P. R., & Ott, T. E. (2011). Action and attentional load can influence aperture effects on motion perception. *Experimental Brain Research*, *209*(2), 215–224. https://doi.org/10.1007/s00221-011-2537-y

DeLucia, P. R., Tresilian, J. R., & Meyer, L. E. (2000). Geometrical illusions can affect time-to-contact estimation and mimed prehension. *Journal of Experimental Psychology: Human Perception and Performance*, *26*(2), 552–567.

DeLucia, P. R., & Warren, R. (1994). Pictorial and motion-based depth information during active control of self-motion: Size-arrival effects on collision avoidance. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(4), 783–798. Retrieved from http://content.apa.org/journals/xhp/20/4/783

Dirnberger, G., Hesselmann, G., Roiser, J. P., Preminger, S., Jahanshahi, M., & Paz, R. (2012). Give it time: Neural evidence for distorted time perception and enhanced memory encoding in emotional situations. *Neuroimage*, *63*(1), 591–599. https://doi.org/10.1016/j.neuroimage.2012.06.041

Droit-Volet, S., & Gil, S. (2009). The time-emotion paradox. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, *364*(1525), 1943–1953. https://doi.org/10.1098/rstb.2009.0013

Droit-Volet, S., & Meck, W. H. (2007). How emotions colour our perception of time. *Trends in Cognitive Sciences*, *11*(12), 504–513. https://doi.org/10.1016/j.tics.2007.09.008

Effron, D. A., Niedenthal, P. M., Gil, S., & Droit-Volet, S. (2006). Embodied temporal perception of emotion. *Emotion*, *6*(1), 1–9. https://doi.org/10.1037/1528-3542.6.1.1

Eimer, M., & Holmes, A. (2007). Event-related brain potential correlates of emotional face processing: The Perception of Emotion and Social Cues in Faces. *Neuropsychologia*, *45*(1), 15–31. https://doi.org/10.1016/j.neuropsychologia.2006.04.022

Fenske, M. J., & Eastwood, J. D. (2003). Modulation of focused attention by faces expressing emotion: evidence from flanker tasks. *Emotion*, *3*(4), 327–343. https://doi.org/10.1037/1528-3542.3.4.327

Ferneyhough, E., Kim, M. K., Phelps, E. A., & Carrasco, M. (2013). Anxiety modulates the effects of emotion and attention on early vision. *Cognition & Emotion*, *27*(1), 166–176. https://doi.org/10.1080/02699931.2012.689953

Field, D. T., & Wann, J. P. (2005). Perceiving time to collision activates the sensorimotor cortex. *Current Biology*, *15*(5), 453–458. https://doi.org/10.1016/j.cub.2004.12.081

Flach, J. M., Smith, M. R. H., Stanard, T., & Dittman, S. M. (2004). Collisions: Getting them under control. In H. Hecht & G. J. P. Savelsbergh (Eds.), *Advances in Psychology: Vol. 135. Time-to-contact* (pp. 67–91). Amsterdam: Elsevier.

Frost, B. J. (2010). A taxonomy of different forms of visual motion detection and their underlying neural mechanisms. *Brain, Behavior and Evolution*, *75*(3), 218–235. https://doi.org/10.1159/000314284

Galton, F. (1890). Exhibition of instruments (1) for testing perception of differences of tint, and (2) for determining reaction-time. *The Journal of the Anthropological Institute of Great Britain and Ireland*, *19*, 27–29. https://doi.org/10.2307/2842529

Gamer, M., & Berti, S. (2012). P300 amplitudes in the concealed information test are less affected by depth of processing than electrodermal responses. *Frontiers in Human Neuroscience*, *6*, 308. https://doi.org/10.3389/fnhum.2012.00308

Geri, G. A., Gray, R., & Grutzmacher, R. (2010). Simulating time-to-contact when both target and observer are in motion. *Displays*, *31*(2), 59–66. https://doi.org/10.1016/j.displa.2009.11.002

Gerritsen, C., Frischen, A., Blake, A., Smilek, D., & Eastwood, J. D. (2008). Visual search is not blind to emotion. *Perception & Psychophysics*, *70*(6), 1047–1059. https://doi.org/10.3758/PP.70.6.1047

Giachritsis, C. D., & Harris, M. G. (2005). Global versus local image expansion in estimating time-to-contact from complex optic flow. *Perception*, *34*(5), 577–585. https://doi.org/10.1068/p5271

Gibson, J. J. (1958/1998). Visually controlled locomotion and visual orientation in animals. *Ecological Psychology*, *10*(3–4), 161–176. https://doi.org/10.1207/s15326969eco103&4_2

Gibson, J. J. (1966). *The senses considered as perceptual system*. Boston: Houghton Mifflin.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Gil, S., & Droit-Volet, S. (2011). "Time flies in the presence of angry faces"… depending on the temporal task used! *Acta Psychologica*, *136*(3), 354–362. https://doi.org/10.1016/j.actpsy.2010.12.010

Gómez-Cuerva, J., & Raymond, J. E. (2011). Perception of facial expression depends on prior attention. *Psychonomic Bulletin & Review*, *18*(6), 1057–1063. https://doi.org/10.3758/s13423-011-0170-1

Gray, R., & Regan, D. (2000). Simulated self-motion alters perceived time to collision. *Current Biology*, *10*(10), 587–590. https://doi.org/10.1016/S0960-9822(00)00493-0

Gray, R., & Regan, D. M. (2006). Unconfounding the direction of motion in depth, time to passage and rotation rate of an approaching object. *Vision research*, *46*(15), 2388–2402. https://doi.org/10.1016/j.visres.2006.02.005

Grommet, E. K., Droit-Volet, S., Gil, S., Hemmes, N. S., Baker, A. H., & Brown, B. L. (2011). Time estimation of fear cues in human observers. *Behavioural Processes*, *86*(1), 88–93. https://doi.org/10.1016/j.beproc.2010.10.003

Gross, C. T., & Canteras, N. S. (2012). The many paths to fear. *Nature Reviews Neuroscience*, *13*(9), 651–658. https://doi.org/10.1038/nrn3301

Halmaoui, H., Hautière, N., Joulan, K., Brémond, R., & Cord, A. (2015). Quantitative model of the driver's reaction time during daytime fog – application to a head up display-based advanced driver assistance system. *IET Intelligent Transport Systems*, *9*(4), 375–381. https://doi.org/10.1049/iet-its.2014.0101

Hanoch, Y., & Vitouch, O. (2004). When less is more: Information, emotional arousal and the ecological reframing of the Yerkes-Dodson Law. *Theory & Psychology*, *14*(4), 427–452. https://doi.org/10.1177/0959354304044918

Harris, J. M., & Dean, Philip J. A. (2003). Accuracy and precision of binocular 3-D motion perception. *Journal of Experimental Psychology: Human Perception and Performance*, *29*(5), 869–881.

Harris, M. G., & Giachritsis, C. D. (2000). Coarse-grained information dominates fine-grained information in judgments of time-to-contact from retinal flow. *Vision research*, *40*(6), 601–611. https://doi.org/10.1016/S0042-6989(99)00209-6

Hecht, H., Hörichs, J., Sheldon, S., Quint, J., & Bowers, A. (2015). The effects of simulated vision impairments on the cone of gaze. *Attention, Perception & Psychophysics*, *77*(7), 2399–2408. https://doi.org/10.3758/s13414-015-0931-4

Hecht, H., & Savelsbergh, G. J. P. (Eds.). (2004). *Time-to-contact. Advances in Psychology: Vol. 135*. Amsterdam: Elsevier.

Hesketh, B., & Godley, S. T. (2002). A comparison of time estimations in driving with target-only in motion, self-only in motion, and self-and-target in motion. *Ecological Psychology*, *14*(3), 111–125. https://doi.org/10.1207/S15326969ECO1403_1

Horswill, M. S., & Plooy, A. M. (2008). Reducing contrast makes speeds in a video-based driving simulator harder to discriminate as well as making them appear slower. *Perception*, *37*(8), 1269–1275. https://doi.org/10.1068/p5821

Hosking, S. G., & Crassini, B. (2010). The effects of familiar size and object trajectories on time-to-contact judgements. *Experimental Brain Research*, *203*(3), 541–552. https://doi.org/10.1007/s00221-010-2258-7

Hugh, T. R., Charlton, S. G., & Perrone, J. A. (2008). The role of looming and attention capture in drivers' braking responses. *Accident Analysis & Prevention*, *40*(4), 1375–1382. https://doi.org/10.1016/j.aap.2008.02.009

Jabłoński, P. G., & Strausfeld, N. J. (2000). Exploitation of an ancient escape circuit by an avian predator: Prey sensitivity to model predator display in the field. *Brain, Behavior and Evolution*, *56*(2), 94–106. https://doi.org/10.1159/000006680

Johansson, G. (1976). Spatio-temporal differentiation and integration in visual motion perception. *Psychological Research*, *38*(4), 379–393. https://doi.org/10.1007/BF00309043

Junghöfer, M., Bradley, M. M., Elbert, T. R., & Lang, P. J. (2001). Fleeting images: A new look at early emotion discrimination. *Psychophysiology*, *38*(02), 175–178. https://doi.org/10.1017/S0048577201000762

Kaschak, M. P., & Maner, J. K. (2009). Embodiment, evolution, and social cognition: An integrative framework. *European Journal of Social Psychology*, *39*(7), 1236–1244. https://doi.org/10.1002/ejsp.664

Kerzel, D., Hecht, H., & Kim, N. G. (1999). Image velocity, not tau, explains arrival-time judgments from global optical flow. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1540–1555.

Kim, N.-G. (2013). The effect of retinal eccentricity on perceiving collision impacts. *Ecological Psychology*, *25*(4), 327–356. https://doi.org/10.1080/10407413.2013.839855

King, S. M., Dykeman, C., Redgrave, P., & Dean, P. (1992). Use of a distracting task to obtain defensive head movements to looming visual stimuli by human adults in a laboratory setting. *Perception*, *21*(2), 245–259.

Klumpp, H., Angstadt, M., & Phan, K. L. (2012). Shifting the focus of attention modulates amygdala and anterior cingulate cortex reactivity to emotional faces. *Neuroscience Letters*, *514*(2), 210–213. https://doi.org/10.1016/j.neulet.2012.03.003

Lake, J. I., LaBar, K. S., & Meck, W. H. (2016). Emotional modulation of interval timing and time perception. *Neuroscience and biobehavioral reviews*, *64*, 403–420. https://doi.org/10.1016/j.neubiorev.2016.03.003

Lambrechts, A., Mella, N., Pouthas, V., & Noulhiane, M. (2011). Subjectivity of time perception: A visual emotional orchestration. *Frontiers in Integrative Neuroscience*, *5*, 73. https://doi.org/10.3389/fnint.2011.00073

Landwehr, K. (2004). Textured tau. In H. Hecht & G. J. P. Savelsbergh (Eds.), *Advances in Psychology: Vol. 135. Time-to-contact* (pp. 229–244). Amsterdam: Elsevier.

Lang, P. J. (1980). Behavioral treatment and bio-behavioral assessment: computer applications. In J. B. Sidowski, J. H. Johnson, & T. A. Williams (Eds.), *Technology in mental health care delivery systems* (pp. 119–137). Norwood, N.J: Ablex Pub. Corp.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2005). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-6*. University of Florida, Gainesville, FL.

Lang, P. J., Davis, M., & Öhman, A. (2000). Fear and anxiety: animal models and human cognitive psychophysiology. *Journal of Affective Disorders*, *61*(3), 137–159. https://doi.org/10.1016/S0165-0327(00)00343-8

Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception*, *5*(4), 437–459. https://doi.org/10.1068/p050437

Lim, C. L., Rennie, C., Barry, R. J., Bahramali, H., Lazzaro, I., Manor, B., & Gordon, E. (1997). Decomposing skin conductance into tonic and phasic components. *International journal of psychophysiology : official journal of the International Organization of Psychophysiology*, *25*(2), 97–109. https://doi.org/10.1016/S0167-8760(96)00713-1

Lin, J. Y., Murray, S. O., & Boynton, G. M. (2009). Capture of attention to threatening stimuli without perceptual awareness. *Current Biology*, *19*(13), 1118–1122. https://doi.org/10.1016/j.cub.2009.05.021

Lindquist, K. A., Wager, T. D., Kober, H., Bliss-Moreau, E., & Barrett, L. F. (2012). The brain basis of emotion: A meta-analytic review. *Behavioral and Brain Sciences*, *35*(03), 121–143. https://doi.org/10.1017/S0140525X11000446

Lipp, O. V., Price, S. M., & Tellegen, C. L. (2009). No effect of inversion on attentional and affective processing of facial expressions. *Emotion*, *9*(2), 248–259. https://doi.org/10.1037/a0014715

Liu, R.-F., Niu, Y.-Q., & Wang, S.-R. (2008). Thalamic neurons in the pigeon compute distance-to-collision of an approaching surface. *Brain, Behavior and Evolution*, *72*(1), 37–47. https://doi.org/10.1159/000145716

López-Moliner, J., Brenner, E., & Smeets, J. B. J. (2007). Effects of texture and shape on perceived time to passage: Knowing "what" influences judging "when". *Perception and Psychophysics*, *69*(6), 887–894.

López-Moliner, J., Field, D. T., & Wann, J. P. (2007). Interceptive timing: Prior knowledge matters. *Journal of Vision*, *7*(13), 1–8. https://doi.org/10.1167/7.13.11

Lui, M. A., Penney, T. B., Schirmer, A., & Meck, W. H. (2011). Emotion effects on timing: Attention versus pacemaker accounts. *PLoS ONE*, *6*(7), e21829. https://doi.org/10.1371/journal.pone.0021829

Mak-Fan, K. M., Thompson, W. F., & Green, R. E. A. (2011). Visual search for schematic emotional faces risks perceptual confound. *Cognition & Emotion*, *25*(4), 573–584. https://doi.org/10.1080/02699931.2010.500159

Marrington, S. A., Horswill, M. S., & Wood, J. M. (2008). The effect of simulated cataracts on drivers' hazard perception ability. *Optometry and Vision Science*, *85*(12), 1121–1127. https://doi.org/10.1097/OPX.0b013e31818e8d00

McGwin, G., JR, Chapman, V., & Owsley, C. (2000). Visual risk factors for driving difficulty among older drivers. *Accident; analysis and prevention*, *32*(6), 735–744. https://doi.org/10.1016/S0001-4575(99)00123-2

McLeod, R. W., & Ross, H. E. (1983). Optic-flow and cognitive factors in time-to-collision estimates. *Perception*, *12*(4), 417–423. https://doi.org/10.1068/p120417

Mills, B. N., Andrey, J., & Hambly, D. (2011). Analysis of precipitation-related motor vehicle collision and injury risk using insurance and police record information for Winnipeg, Canada. *Journal of safety research*, *42*(5), 383–390. https://doi.org/10.1016/j.jsr.2011.08.004

Mueller, A. S., & Trick, L. M. (2012). Driving in fog: the effects of driving experience and visibility on speed compensation and hazard avoidance. *Accident; analysis and prevention*, *48*, 472–479. https://doi.org/10.1016/j.aap.2012.03.003

Münch, T. A., da Silveira, R. A., Siegert, S., Viney, T. J., Awatramani, G. B., & Roska, B. (2009). Approach sensitivity in the retina processed by a multifunctional neural circuit. *Nature Neuroscience*, *12*(10), 1308–1316. https://doi.org/10.1038/nn.2389

National Eye Institute. (2015). Facts about cataract. Retrieved from https://nei.nih.gov/health/cataract/cataract_facts#3a

Ni, R., Bian, Z., Guindon, A., & Andersen, G. J. (2012). Aging and the detection of imminent collisions under simulated fog conditions. *Accident; analysis and prevention*, *49*, 525–531. https://doi.org/10.1016/j.aap.2012.03.029

Ni, R., Kang, J. J., & Andersen, G. J. (2010). Age-related declines in car following performance under simulated fog conditions. *Accident Analysis & Prevention*, *42*(3), 818–826. https://doi.org/10.1016/j.aap.2009.04.023

Nikitin, J., & Freund, A. M. (2010). *Faster in getting closer than in getting away*. Poster presented at the 11th Annual Meeting of the Society for Personality and Social Psychology, Las Vegas, NV, USA.

Novak, J. L. B. (1997). *Judgments of absolute time-to-contact in multiple object displays: Evaluating the role of cognitive processes in arrival-time judgments* (Ph.D. dissertation). Texas Tech University, United States, Texas. Retrieved from http://hdl.handle.net/2346/16958

Oberfeld, D., & Hecht, H. (2008). Effects of a moving distractor object on time-to-contact judgments. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(3), 605–623. https://doi.org/10.1037/0096-1523.34.3.605

Oberfeld, D., Hecht, H., & Landwehr, K. (2011). Effects of task-irrelevant texture motion on time-to-contact judgments. *Attention, Perception & Psychophysics*, *73*(2), 581–596. https://doi.org/10.3758/s13414-010-0040-3

Ohman, A., & Soares, J. J. (1993). On the automatic nature of phobic fear: conditioned electrodermal responses to masked fear-relevant stimuli. *Journal of Abnormal Psychology*, *102*(1), 121–132.

Öhman, A. (1986). Face the beast and fear the face: Animal and social fears as prototypes for evolutionary analyses of emotion. *Psychophysiology*, *23*(2), 123–145. https://doi.org/10.1111/j.1469-8986.1986.tb00608.x

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General*, *130*(3), 466–478.

Öhman, A., Juth, P., & Lundqvist, D. (2010). Finding the face in a crowd: Relationships between distractor redundancy, target emotion, and target gender. *Cognition & Emotion*, *24*(7), 1216–1228. https://doi.org/10.1080/02699930903166882

Öhman, A., Lundqvist, D., & Esteves, F. (2001). The face in the crowd revisited: A threat advantage with schematic stimuli. *Journal of Personality and Social Psychology*, *80*(3), 381–396. https://doi.org/10.1037/0022-3514.80.3.381

Öhman, A., & Soares, J. J. F. (1994). "Unconscious anxiety": phobic responses to masked stimuli. *Journal of Abnormal Psychology*, *103*, 231–240. https://doi.org/10.1037/0021-843X.103.2.231

Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: An integrative review of ERP findings. *Biological Psychology*, *77*(3), 247–265. https://doi.org/10.1016/j.biopsycho.2007.11.006

Owsley, C., Stalvey, B. T., Wells, J., Sloane, M. E., & McGwin, G., JR (2001). Visual risk factors for crash involvement in older drivers with cataract. *Archives of ophthalmology*, *119*(6), 881–887. https://doi.org/10.1001/archopht.119.6.881

Pallett, P. M., & MacLeod, D. I. A. (2011). Seeing faces as objects: No face inversion effect with geometrical discrimination. *Attention, Perception & Psychophysics*, *73*(2), 504–520. https://doi.org/10.3758/s13414-010-0033-2

Pelli, D. G., Robson, J. G., & Wilkins, A. J. (1988). The design of a new letter chart for measuring contrast sensitivity. *Clinical Vision Sciences*, *2*(3), 187–199.

Pessoa, L., Kastner, S., & Ungerleider, L. G. (2002). Attentional control of the processing of neutral and emotional stimuli. *Cognitive Brain Research*, *15*(1), 31–45. https://doi.org/10.1016/S0926-6410(02)00214-8

Phelps, E. A., Ling, S., & Carrasco, M. (2006). Emotion facilitates perception and potentiates the perceptual benefits of attention. *Psychological Science*, *17*(4), 292–299. https://doi.org/10.1111/j.1467-9280.2006.01701.x

Pössel, P., & Hautzinger, M. (2002). Spinnen-Angst-Fragebogen (SAF). Validierung der deutschen Version des "Fear of Spiders Questionnaire" (FSQ). *Zeitschrift für Klinische Psychologie, Psychiatrie und Psychotherapie*, *50*(2), 207–218.

Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on psychological science : a journal of the Association for Psychological Science*, *1*(2), 110–122. https://doi.org/10.1111/j.1745-6916.2006.00008.x

Purcell, D. G., & Stewart, A. L. (2010). Still another confounded face in the crowd. *Attention, Perception, & Psychophysics*, *72*(8), 2115–2127. https://doi.org/10.3758/APP.72.8.2115

Raymond, J. E. (2000). Attentional modulation of visual motion perception. *Trends in Cognitive Sciences*, *4*(2), 42–50. https://doi.org/10.1016/S1364-6613(99)01437-0

Regan, D. (1992). Visual judgements and misjudgements in cricket, and the art of flight. *Perception*, *21*(1), 91–115. https://doi.org/10.1068/p210091

Roelofs, K., Hagenaars, M. A., & Stins, J. (2010). Facing freeze: Social threat induces bodily freeze in humans. *Psychological Science*, *21*(11), 1575–1581. https://doi.org/10.1177/0956797610384746

Rushton, S. K., & Wann, J. P. (1999). Weighted combination of size and disparity: a computational model for timing a ball catch. *Nature Neuroscience*, *2*(2), 186–190. https://doi.org/10.1038/5750

Sabatinelli, D., Fortune, E. E., Li, Q., Siddiqui, A., Krafft, C., Oliver, W. T.,. . . Jeffries, J. (2011). Emotional perception: Meta-analyses of face and natural scene processing. *Neuroimage*, *54*(3), 2524–2533. https://doi.org/10.1016/j.neuroimage.2010.10.011

Schiff, W. (1965). Perception of impending collision: A study of visually directed avoidant behavior. *Psychological Monographs*, *79*(11), 1–26. https://doi.org/10.1037/h0093887

Schiff, W., & Oldak, R. (1990). Accuracy of judging time to arrival: Effects of modality, trajectory, and gender. *Journal of Experimental Psychology: Human Perception and Performance*, *16*(2), 303–316.

Shi, Z., Jia, L., & Müller, H. J. (2012). Modulation of tactile duration judgments by emotional pictures. *Frontiers in Integrative Neuroscience*, *6*, 24. https://doi.org/10.3389/fnint.2012.00024

Smith, M. R., Flach, J. M., Dittman, S. M., & Stanard, T. (2001). Monocular optical constraints on collision control. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(2), 395–410. https://doi.org/10.1037/0096-1523.27.2.395

Smith, N. K., Cacioppo, J. T., Larsen, J. T., & Chartrand, T. L. (2003). May I have your attention, please: Electrocortical responses to positive and negative stimuli. *Neuropsychologia*, *41*(2), 171–183.

Snowden, R. J., Stimpson, N., & Ruddle, R. A. (1998). Speed perception fogs up as visibility drops. *Nature*, *392*(6675), 450. https://doi.org/10.1038/33049

Stewart, D., Cudworth, C. J., & Lishman, J. R. (1993). Misperception of time-to-collision by drivers in pedestrian accidents. *Perception*, *22*(10), 1227–1244.

Stewart, D. L., Cudworth, C. J., & Lishman, J. R. (1997). Response to the critical note "Correcting some misperceptions of time-to-collision" by James R Tresilian. *Perception*, *26*(2), 237–241. https://doi.org/10.1068/p260237

Stoffregen, T. A., & Riccio, G. E. (1990). Responses to optical looming in the retinal center and periphery. *Ecological Psychology*, *2*(3), 251–274. https://doi.org/10.1207/s15326969eco0203_3

Thibos, L. N., & Thibos, C. A. (2011). Geometrical optical analysis of defocused retinal images to compute the size of retinal blur circles relative to object size. *US Ophthalmic Review*, *04*(02), 104. https://doi.org/10.17925/USOR.2011.04.02.104

Thomas, P. M. J., Jackson, M. C., & Raymond, J. E. (2014). A threatening face in the crowd: Effects of emotional singletons on visual working memory. *Journal of experimental psychology. Human perception and performance*, *40*(1), 253–263. https://doi.org/10.1037/a0033970

Tipples, J. (2011). When time stands still: Fear-specific modulation of temporal bias due to threat. *Emotion*, *11*(1), 74–80. https://doi.org/10.1037/a0022015

Tipples, J., Young, A. W., Quinlan, P., Broks, P., & Ellis, A. W. (2002). Searching for threat. *The Quarterly Journal of Experimental Psychology Section A*, *55*(3), 1007–1026. https://doi.org/10.1080/02724980143000659

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A.,. . . Nelson, C. (2009). The NimStim set of facial expressions: judgments from untrained research participants. *Psychiatry research*, *168*(3), 242–249. https://doi.org/10.1016/j.psychres.2008.05.006

Tresilian, J. R. (1995). Perceptual and cognitive processes in time-to-contact estimation: Analysis of prediction-motion and relative judgment tasks. *Perception & Psychophysics*, *57*(2), 231–245. https://doi.org/10.3758/BF03206510

Tresilian, J. R. (1997). Correcting some misperceptions of time-to-collision: a critical note. *Perception*, *26*(2), 229–236.

Tresilian, J. R. (1999). Visually timed action: time-out for 'tau'? *Trends in Cognitive Sciences*, *3*(8), 301–310. https://doi.org/10.1016/S1364-6613(99)01352-2

Vagnoni, E., Lourenco, S. F., & Longo, M. R. (2012). Threat modulates perception of looming visual stimuli. *Current Biology*, *22*(19), R826-R827. https://doi.org/10.1016/j.cub.2012.07.053

Vagnoni, E., Lourenco, S. F., & Longo, M. R. (2015). Threat modulates neural responses to looming visual stimuli. *The European journal of neuroscience*, *42*(5), 2190–2202. https://doi.org/10.1111/ejn.12998

van der Horst, A. R. A. (1990). *A time-based analysis of road user behaviour in normal and critical encounters* (PhD Thesis). TU Delft, Soesterberg, Netherlands. Retrieved from http://resolver.tudelft.nl/uuid:8fb40be7-fae1-4481-bc37-12a7411b85c7

van Le, Q., Isbell, L. A., Matsumoto, J., Nguyen, M., Hori, E., Maior, R. S.,. . . Nishijo, H. (2013). Pulvinar neurons reveal neurobiological evidence of past selection for rapid detection of snakes. *Proceedings of the National Academy of Sciences.* Advance online publication. https://doi.org/10.1073/pnas.1312648110

van Winsum, W., & Heino, A. (1996). Choice of time-headway in car-following and the role of time-to-collision information in braking. *Ergonomics*, *39*(4), 579–592. https://doi.org/10.1080/00140139608964482

Vasey, M. W., Vilensky, M. R., Heath, J. H., Harbaugh, C. N., Buffington, A. G., & Fazio, R. H. (2012). It was as big as my head, I swear! Biased spider size estimation in spider phobia. *Journal of Anxiety Disorders*, *26*(1), 20–24. https://doi.org/10.1016/j.janxdis.2011.08.009

Venables, P. H., & Christie, M. J. (1980). Electrodermal activity. In I. Martin & P. H. Venables (Eds.), *Advances in the study of communication and effect: Vol. 6. Techniques in psychophysiology* (pp. 3–67). Chichester, UK: Wiley.

Vincent, A., & Regan, D. (1997). Judging the time to collision with a simulated textured object: effect of mismatching rate of expansion of object size and of texture element size. *Perception and Psychophysics*, *59*(1), 32–36. https://doi.org/10.3758/BF03206845

Vogel, K. (2003). A comparison of headway and time to collision as safety indicators. *Accident; analysis and prevention*, *35*(3), 427–433. https://doi.org/10.1016/S0001-4575(02)00022-2

Wager, T. D., Barrett, L. F., Bliss-Moreau, E., Lindquist, K. A., Duncan, S., Kober, H.,. . . Mize, J. (2008). The neuroimaging of emotion. In M. Lewis, J. M. Haviland-Jones, & L. Feldman Barrett (Eds.), *Handbook of emotions* (3rd ed., pp. 249–271). New York: Guilford Press.

Wang, Y., & Frost, B. J. (1992). Time to collision is signalled by neurons in the nucleus rotundus of pigeons. *Nature*, *356*, 236–238. https://doi.org/10.1038/356236a0

Wangelin, B. C., Bradley, M. M., Kastner, A., & Lang, P. J. (2012). Affective engagement for facial expressions and emotional scenes: The influence of social anxiety. *Biological Psychology*, *91*(1), 103–110. https://doi.org/10.1016/j.biopsycho.2012.05.002

Welchman, A. E., Tuck, V. L., & Harris, J. M. (2004). Human observers are biased in judging the angular approach of a projectile. *Vision research*, *44*(17), 2027–2042. https://doi.org/10.1016/j.visres.2004.03.014

West, G., Al-Aidroos, N., Susskind, J., & Pratt, J. (2011). Emotion and action: the effect of fear on saccadic performance. *Experimental Brain Research*, *209*(1), 153–158. https://doi.org/10.1007/s00221-010-2508-8

West, G. L., Anderson, A. A. K., Ferber, S., & Pratt, J. (2011). Electrophysiological evidence for biased competition in V1 for fear expressions. *Journal of Cognitive Neuroscience*, *0*(0), 1–10. https://doi.org/10.1162/jocn.2011.21605

Wilson-Mendenhall, C. D., Barrett, L. F., Simmons, W. K., & Barsalou, L. W. (2011). Grounding emotion in situated conceptualization. *Neuropsychologia*, *49*(5), 1105–1127. https://doi.org/10.1016/j.neuropsychologia.2010.12.032

Wood, J. M., & Owens, D. A. (2005). Standard measures of visual acuity do not predict drivers' recognition performance under day or night conditions. *Optometry and Vision Science*, *82*(8), 698–705. https://doi.org/10.1097/01.opx.0000175562.27101.51

Xiao, Q., & Frost, B. J. (2009). Looming responses of telencephalic neurons in the pigeon are modulated by optic flow. *Brain Research*, *1305*, 40–46. https://doi.org/10.1016/j.brainres.2009.10.008

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*(5), 459–482. https://doi.org/10.1002/cne.920180503

Yilmaz, M., & Meister, M. (2013). Rapid innate defensive responses of mice to looming visual stimuli. *Current biology : CB*, *23*(20), 2011–2015. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0960982213009913

Yonas, A., Bechtold, A. G., Frankel, D., Gordon, F. R., McRoberts, G., Norcia, A., & Sternfels, S. (1977). Development of sensitivity to information for impending collision. *Perception & Psychophysics*, *21*(2), 97–104. Retrieved from http://www.psychonomic.org/backissues/18981//pp/vol21-2/pp-21-97.pdf

Zhang, D., Liu, Y., Wang, X., Chen, Y., & Luo, Y. (2014). The duration of disgusted and fearful faces is judged longer and shorter than that of neutral faces: the attention-related time distortions as revealed by behavioral and electrophysiological measurements. *Frontiers in behavioral neuroscience*, *8*, 293. https://doi.org/10.3389/fnbeh.2014.00293