Threat Determines Affective Startle Potentiation

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Abstract—**Affective startle modulation often is attributed to the valence dimension of applied foreground stimuli, whereas alternative views refer to specific discrete emotions. Based on the idea of the startle reflex being a protective mechanism, the significance of threat to the acoustic startle response was tested. Affectively charged pictures were selected according to their quantified discrete-emotional distinctness: pictures primarily evoking sadness, anger, and disgust (low valence); pictures primarily evoking fear (threat; *moderately* low valence); and pictures primarily evoking happiness (high valence). Electromyography (EMG) of the orbicularis oculi muscle revealed substantial startle potentiation by the fear evoking stimuli. Moreover, evidence was found that disgust bears a strong relation to the startle reflex. In line with other recent studies the reported findings suggest that startle is being increased by threat to one's physical integrity, as is signaled by the discrete emotions of fear and disgust.**

Startle; threat; discrete emotions; fear; disgust; dimensions; valence; arousal

I. Introduction

It is a widespread notion that the valence of presented foreground stimuli, e.g. pictures or sounds, determines the magnitude of a concomitantly elicited startle response. In this *dimensional* view, 'negative' (i.e. low-valence) stimuli potentiate the startle reflex, while 'positive' (i.e. high-valence) stimuli alleviate it [1]. Virtually since introduction of startle modulation as an indicator of emotional states [2], this opinion prevails in theory as well as in experimental practice. It can probably be seen as one of the most influencing and often replicated findings favoring a dimensional view on emotions.

This is the case in face of a large body of evidence for fear-potentiated startle [3], drawing threat into the focus of attention. One of the first results mentioned by [1] in their influencing early review on affective startle shows strong potentiation by learned fear [4]. Further, neural models link startle potentiation to the amygdala [5, 6], a brain structure commonly associated with the processing of fear.[1] Of course, these findings do not exclude the possibility, that non-fear low-valence emotional states potentiate startle responses.

More basic evidence for the significance of specific *discrete* emotions comes from the physiological account of the eye lid closing reflex, also known as the 'corneal' or the 'blink reflex', as part of a protective mechanism [9]. At least regarding potentiation, it provides an independent intuition that involuntary blinks should only be affected by such foreground stimuli the potentially harmful effects of which could be avoided by fast motor responses. From this perspective, other 'negative' stimuli should not potentiate startle blinks. To decide this issue, classical threat (fear-evoking) and non-fear low-valence stimuli were compared.

One reason for ambiguous results of previous studies might be that low valence can result from harmless and threatening aversive stimuli as well. Furthermore, stimuli virtually never evoke discrete emotions with absolute selectivity, which shows e.g. in studies deriving discrete-emotional ratings for affective pictures [10]. So, if stimuli are not inspected meticulously regarding the discrete emotions they evoke, threat can occur covertly, and the impression might easily arise that valence modulates the startle reflex.

Despite differences in various physiological and motor responses, e.g. [11] were not able to find differential startle magnitudes to fear and anger evoking imagery. They regarded their findings as a confirmation of startle modulation reflecting a more basic priming of emotional or motivational states, as hypothesized by [1]. However, the method of affective imagery does not allow for a reliable predetermination of the discrete emotions to evoke, because stimulus material is constructed within participants' minds (see also [12] for a comparison of disgust and anger with similar problems). Also, [11] did not check for distinct manipulation on a postexperimental basis. Further, the comparison of fear and anger evoking stimuli seems not very well suited for clearing the dispute at hand. Anger evoking situations often suggest an impending conflict between individuals, bearing the potential of violent escalation. Thus they imply a certain degree of fear on either side.

Anger evoking stimuli thoroughly controlled for fear elicitation should not substantially potentiate the startle reflex. Nevertheless, it is not easy to conceive of good candidates. Stimuli depicting acts of discrimination or eliciting concerns about environmental damage might turn out to elicit anger but not fear. On the other hand, their effects likely are subject to high interindividual variability. To adequately deal with this problem, various non-fear 'negative' emotions must be considered. So, the present study compared low-valence stimuli primarily evoking the discrete emotions of sadness, anger, and disgust with others primarily evoking fear regarding their potential to increase the startle reflex.

[1] Newer work aims at linking the amygdala to valence processing [7, 8], but this issue is far from decided.

II. Method

A. Participants and recruitment:

Thirty-six participants (19–30 years, m=23; 18 female), mostly undergraduate psychology students, receiving partial course credit for compensation. All participants had a Western European background. They were informed that they would view pictures of various emotional and possibly distressful content and would repeatedly be exposed to loud noise; they provided written consent.

B. Stimuli:

Stimuli from the International Affective Picture System (IAPS) [13] were selected for being as distinct as possible with respect to the discrete emotions they evoke. The first stimulus category contained pictures primarily evoking sadness, anger, and disgust ('low-valence'), with fear being as insignificant as possible. The second category contained pictures primarily evoking fear ('threat'). From a dimensional view, both evoke emotional states denoted as 'negative' and thus are expected to potentiate startle blinks. The third category contained pictures primarily evoking happiness ('high-valence').

Stimulus selection was based on a simple statistic. Reference [10] reported discrete-emotional intensity ratings of the IAPS pictures for the emotions listed above. To derive a selection criterion, for every picture the intensity-independent distinctness of each emotion was determined by computing the ratio of an emotional intensity and the maximum intensity of the respective other emotions. This lead to (1) a discrete-emotional assignment for every picture according to its *dominant* emotion, denoted by the maximum distinctness, and (2) optimal selection regarding the standard outlined above.[2] For illustration purposes this ratio was rescaled mapping the distinctnesses of the dominant emotions onto the interval between zero (maximum ambiguity) and unity (maximum distinctness; found within the 'high-valence' category), resulting in negative values for the nondominant emotions.

After selection of the 18 most distinct non-fear low-valence (6 each for sadness, anger and disgust), fear, and happiness conveying pictures, some manual refinement was applied. Basically, it was assured that no picture would be presented the intended emotional content of which appeared to rely on a specific cultural, social, educational, or age background not shared by the participants. A list of the final set of 54 highly distinct stimuli can be obtained from the corresponding author.

C. Verification of stimulus validity:

Fig. 1 shows the distinctnesses of the discrete emotions evoked by each stimulus category. To derive a single non-fear low-valence distinctness, each picture's dominant 'negative' emotion aside from fear was accounted for. Obviously, each stimulus category evokes its dominant emotion(s) most

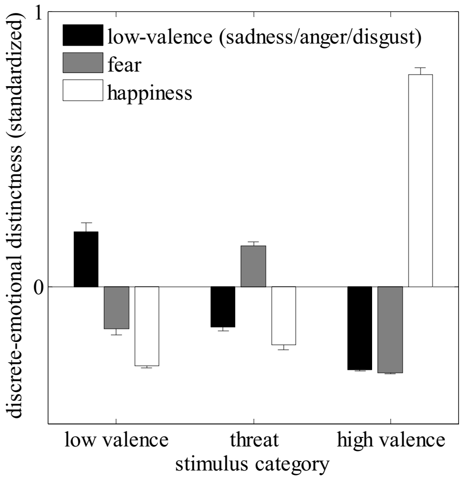

Figure 1. Standardized distinctness (means and standard errors) of discrete emotions evoked by the stimulus categories; for the non-fear low-valence emotions (black), each picture's highest sadness, anger, or disgust distinctness was determined. On a single-stimulus level zero denotes maximum ambiguity.

distinctly. Further, the low-valence and the threat category do not differ significantly in their dominant emotion's distinctness ($t=1.360$, $p=0.187$, two-tailed). Unfortunately, the dominant emotion's intensity (data not shown) is significantly lower for the threat ($m=5.10$) than for the low-valence category ($m=6.43$, $p<0.001$). So lower startle potentiation by the former could be due to a difference in category significance. Fig. 2 illustrates the distribution of the selected stimuli in valence/arousal space grouped by dominant discrete emotion; plotted are the coordinates reported by [13]. Clearly, the low-valence and the threat stimuli exhibit lower valence than the high-valence stimuli. Notably, the low-valence stimuli were rated even lower in valence than the threat stimuli ($t=5.413$, $p<0.001$). Together, the distinctness and the valence relation of the low-valence and the threat category imply a highly stringent comparison of the two perspectives under scrutiny. Finally, although the startle

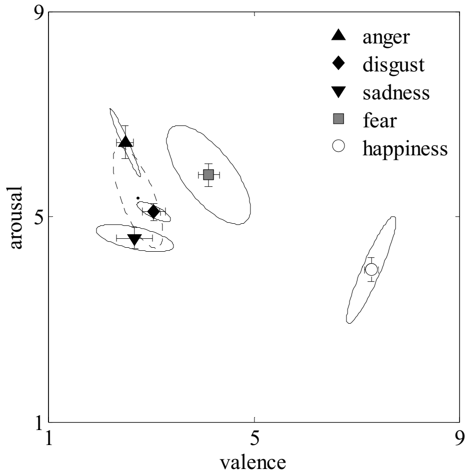

Figure 2. Distribution of stimuli in valence/arousal space grouped by dominant emotion: symbols represent category means (with standard errors), ellipsoids resemble direction and extent of the orthogonal main variance components, given by eigenvectors of the matrices of covariance; the dotted line indicates the distribution of the composite low-valence category (black).

[2] Of course, although intensity and distinctness are substantially correlated ($r=0.46$ for the dominant emotions), this approach did not necessarily lead to the strongest emotion elicitation. If startle modulation depends on fear, its intensity, rather than its distinctness, provides the best prediction. However, the goal of the present study was not to maximize startle but to distinguish between two alternative explanatory concepts.

response is commonly known not to be arousal sensitive [1], it was ensured that the two 'negative' categories herein do not differ significantly (t=1.368, p=0.180, two-tailed).

D. Procedure:

Participants were seated in a sound attenuating booth, viewing the selected IAPS pictures on a 20" LCD screen. They were instructed to imagine being present in the depicted situations as vividly as possible. They were told to ignore the occasionally occurring noise (the startle probe), a nearly instantaneous 50 ms white noise burst at 95 dB, administered via calibrated headphones.

After 1 min (20 bursts) of prehabituation the whole stimulus set was presented twice in independent experimental runs; the procedure was kept close to one applied by [14]. The startle probe was administered pseudorandomly during 2/3 of all presentations, and to further reduce predictability, it was presented between trials a total number of 24 times. Each presentation of a picture was preceded by a blank of 10–18 s. Subsequently the emotional pictures were presented for 6s and, on probed trials, the regular startle probe occurred with a stimulus onset asynchrony (SOA) of 2.5–5.5 s A complete session took about an hour, and afterwards participants were thanked, debriefed on the particular purpose of the experiment, asked for confidentiality, rewarded, and dismissed.

E. EMG measurement and quantification:

EMG data were collected by a "NeXus-16" bioamplifier (Mind Media BV, NL) attached to Ag/AgCl-based electrodes, which were placed directly over the m. orbicularis oculi, under the left eye for right-handed participants. The electric raw signal was amplified, digitized (24 bit), bandpass filtered to a frequency range of 50–200 Hz, and RMS transformed with a time constant of 1/16 s; the final signal had a sampling rate of 32 Hz. Superficial visual inspection was undertaken to ensure that no major (nonphysiological) artifacts were present in the data.

Startle blinks were quantified as the maximum signal differences to baseline larger than 1 μV which are observed within 30–120 ms after startle probe onset. Baseline was determined as the mean signal within 30 ms before to 30 ms after startle probe onset. Startle blinks smaller than 1 μV were set to zero. 5 Participants (3 female) with an overall startle magnitude of less than 1 μV were excluded as low responders, which was equivalent to a criterion of 1/3 or less valid startle blinks. This prevented increasing (with decreasing magnitude) error variance to be overrepresented in the data. To account for differences in skin/electrode conductance and individual startle reactivity, participants' data were standardized through division by their respective grand mean. This reduced the selective impact of high responders and assured differences between single means to be comparable across participants, allowing for the application of parametric statistical tests.

III. Results

Paired t-tests revealed that the threat category produced significantly higher startle magnitudes than the high-valence (t=4.092, p<0.001) and the low-valence (t=3.533, p<0.001) category. These findings confirm the intuition that fear evoked in viewers of emotional pictures is more important for affective startle potentiation than low valence. Noteworthy, the difference of startle magnitudes of the low-valence and the high-valence category (t=1.557, p=0.130, two-tailed) does not allow for the conclusion that low valence by itself effects any startle potentiation at all.

Fig. 3 shows the mean startle blink magnitudes of female and male participants as a function of stimulus category. Due to standardization, gender effects were assessed by comparing within-subject differences across groups. Unpaired t-tests revealed that differences between the threat and the high-valence stimuli are more pronounced for female than for male participants (t=2.030, p=0.026). No other comparison reached significance. Two things shall be noted: First, this finding is in line with other studies reporting affective startle modulation to be more effective in women than in men. This was shown either regarding disgust [15] or unspecific low-valence stimuli [16–18]. Second, and more central to the purpose of this study, if startle potentiation relies on fear, it is highly plausible that gender effects could only be demonstrated if analysis involves the threat category.

Effects of the low-valence category could be obscured because of its composite nature. To see whether valence plays a role secondary to fear in startle potentiation, correlations within the threat category were inspected. Significant correlations with startle magnitude were found for valence (r=–0.565) and related measures (happiness; the sum of the 'negative' emotional ratings; p<0.05 all). Unfortunately, disgust ratings correlate even stronger with startle magnitude (r=0.743, p<0.001). If controlled for disgust by means of partialization, the former correlations vanish (valence: r=–0.109, p=0.667). This result indicates disgust, rather than valence, being secondary to fear in its significance to affective startle. Further, it underlines the view that the relation of valence to startle is due to the contribution of specific discrete emotions.

To explore the role of disgust, the non-fear 'negative' emotions were examined in detail. Fig. 4 shows the respective mean startle blinks according to the two experimental runs. It can be seen that, although substantial habituation is observed from the first to the second presentation, the pattern of means remains largely unchanged. This replication is supporting the robustness of the collapsed means (across runs) and of their subsequent post-hoc analyses. Paired t-tests revealed that the disgusting pictures effected significantly higher startle magnitudes than the saddening pictures (t=2.449, p=0.010), whereas magnitudes for the anger evoking pictures were not significantly different to either (p>0.15 both). This result confirms the correlational finding that aside from fear not all of the other 'negative' discrete emotions remain neutral regarding startle potentiation. Disgust plays a role at least secondary to fear, being largely accountable for the marginally significant startle potentiation found for the low-valence category. Sadness, on the other hand, is rather insignificant to affective startle—if not alleviating it, as the mean difference to the high-valence category could be indicative of—showing most clearly that low valence is not sufficient for potentiating the startle response. The role of anger remains unclear so far, this issue will be addressed in the discussions section.

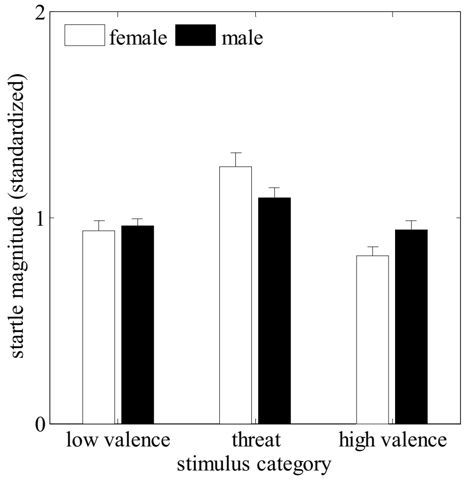

Figure 3. Standardized startle blinks of female and male participants as a function of stimulus category; 'low valence' spares fear most effectively.

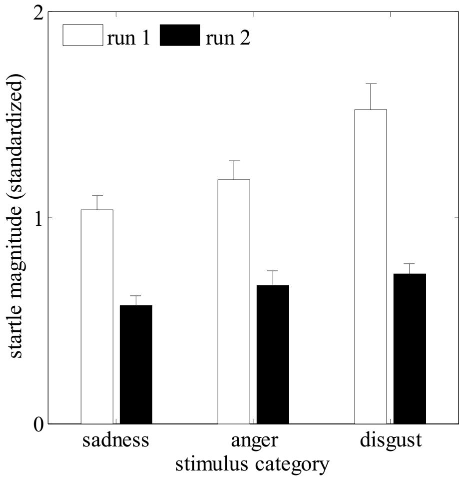

Figure 4. Standardized startle blinks pertinent to independent experimental runs as a function of non-fear low-valence discrete-emotional subcategory.

Taken together, the presented results can provide no evidence that valence plays any role in affective startle modulation. Rather they suggest that low valence appears to be influencing the startle reflex only as far as it is mediated by the discrete emotions of fear and disgust.

IV. Discussion

The goal of the present study was to clarify the issue whether valence in general or rather the contribution of specific threat-mediating discrete emotions to the affective 'content' of stimuli determine the potentiation of the startle reflex. In order to successfully discriminate between low valence and threat, picture categories were created that verifiably elicit the underlying 'negative' emotions most distinctly. As a measure of amplification, participants were instructed to imagine to be present in the depicted situations as vividly as possible.

That way, substantial startle potentiation pertinent to classical threat (i.e. posing a 'fight or flight' challenge) was demonstrated, showing that valence can not be the crucial factor for affectively modulated startle. Rejection of the dimensional view was strengthened by the fact that the selected threat-mediating stimuli actually bear higher valence than the low-valence stimuli. Three results further underline this interpretation: First, gender differences in startle potentiation, determined as differences to the high-valence category, could only be found for the threat category. Second, focusing on the latter, a robust correlation with startle magnitude could only be found for the discrete emotion of disgust.[3] Third, if the low-valence category is inspected closer, only disgust (vs. anger and sadness) seems to effect substantial startle potentiation.

These observations all favor the discrete-emotions view on affective startle modulation, having originated in the intuition of the startle reflex being sensitive to threat. Still, not all non-fear 'negative' emotions remain neutral: disgust appears to have a comparably tight relation to the startle reflex as is the case for fear. Given the conceptualization of startle as a protective reflex this is not surprising, because many stimuli evoking disgust can as well be regarded as posing some kind of threat. Of course, 'threat' in this formulation can not be restricted to the classical fear domain, i.e. threat of attack, injure, and death. It has to be taken in a wider notion including threat of contamination, poisoning, and intrusion of arthropods (insects, spiders, centipedes etc.) and parasites. Obviously, fear and disgust both resemble (or go along with) concerns regarding one's physical integrity. Compatible with this idea are findings that fear and disgust are hardly separable in spider phobia, a disorder known to be indicated by a potentiated startle reflex during exposure [19]. E.g., pictures of spiders evoke fear and disgust nearly equally in spider phobics [20], and disgust sensitivity appears to play a role in the development of fear of spiders [21]. Furthermore, there is evidence that brain structures typically associated with disgust processing are activated during fear processing as well [22]. Another hint on the connection between fear and disgust comes from data showing massive startle potentiation especially for mutilation pictures [23], for which a rough inspection of the discrete-emotional rating data reported by [10] (cf. Methods), besides substantial fear ratings, confirm disgust as their dominantly elicited discrete emotion. Similar results are reported by [15], showing moderate startle potentiation for fear and for disgust stimuli, but large effects for blood-related disgust, presumably comprising the elicitation of disgust as well as fear. Following this line of thought, the extended

[3] Correlational analysis was restricted to threat, because this category bears substantial variance in valence (cf. Fig. 2), and this variance is not due to variations in discrete emotion. A low correlation of startle magnitude with valence for the whole stimulus set also exists (r=-0.278, p=.042), but this must be expected from the startle potentiation found for the fear-evoking and disgusting pictures. One reviewer pointed to the possibility of a nonlinear relation between valence and startle magnitude with a peak at some mid value. The same argument as above applies: a tendency for such a relation must be expected from the given pattern of startle potentiation (cf. Fig. 3), and it can not be decided whether this is due to valence or discrete emotions. However, from a dimensional view postulating such a relation would be to claim that rather insignificant stimuli should augment the startle reflex most strongly, which seems not intuitive to the authors. They stick to the rationale that, if startle magnitude depends on valence and at least some variability in valence is given, a (robust) relation between valence and startle magnitude should show irrespective of stimulus category.

hypothesis can be formulated that affective startle modulation largely depends on a threat to one's physical integrity, which is explicitly meant in the sense of fear and disgust.

Two possible criticisms to the emotional validity of the stimulus set shall be addressed briefly. To begin with, for lack of a true baseline, a stimulus category predominantly evoking happiness was applied as a common comparison category for the two 'negative' categories. A difference in startle magnitude to the former is interpreted as startle potentiation. Of course, the role of high valence regarding affective startle is not yet clear: see [24] for evidence that erotic stimuli alleviate the startle reflex, while adventurous pictures rather increase it. Anyway, because the high-valence category as a whole is not expected to substantially increase startle, it appears to be an appropriate contrasting condition.

More serious, it is essential to assure that the low-valence category had an emotional significance to the participants similar to that of the threat category. The fact that startle potentiation by the low-valence category is only marginally significant might be due to problems of stimulus selection.

To begin with, there appears to be no reason to doubt the significance of the selected disgusting stimuli. Concluded from picture content, mostly insects (cockroaches, flies) on food, dirt and excrements, they can be viewed as face-valid. Of course, one could speculate that not all depicted disgust-related threats might be avoided by a fast movement, but the effected startle magnitudes stand for themselves. Particularly, the stimuli appear to be sufficiently transcultural. Cultural specificity is a possible objection to the reported stimulus properties, i.e. the assumed emotion elicitation, because valence and arousal norms and discrete emotional rating data are derived from northern American samples (cf. Methods). Further, the interpretation of stimuli might especially be culturally biased if individuals are depicted who are involved in some kind of social interaction. So, the actual emotional effects of the presented pictures could vary regarding valence and arousal as well as discrete-emotional intensities. However, deviations in valence, which must be viewed as most critical to the purpose of the study, can be widely neglected, because the respective relation of the competing categories ('low valence' < 'threat') provides some buffer to the experimental antecedents. Therefore, only the discrete-emotional aspects of stimulus selection shall be discussed.

The selected anger evoking pictures turn out to disproportionately often show violence involving two or more persons. This is surprising, because following the arguments presented above (s. Introduction), these stimuli, aside from anger, should substantially evoke fear. Maybe, because the violent acts mostly are committed by young African-American males, the anger advantage of these stimuli relies in part on social psychological mechanisms. To some degree the latter might prevent fear elicitation by some form of secureness-conveying out-group attribution of the depicted situations. Anyhow, these pictures show a theme which is not so common in Western European countries. So, in the present experiment they might not have evoked anger as strongly as would be the case for US-American participants, even if part of the affective content should be interpretable without recourse to ethnic concepts. Also the anger evoking stimuli exhibit the far lowest discrete-emotional distinctness. Actually, preliminary analysis of their emotional intensities reveals that they evoke all 'negative' emotions quite strongly. In part this may resemble a general problem with eliciting anger by the use of pictures. On the other hand, the two most distinct anger-evoking pictures were eliminated due to questionable emotional validity to German undergraduate students: namely, IAPS picture 7590 (traffic holdup at night) and 5940 (most likely an explosion on a country road). Nevertheless, because these stimuli generally bear quite low intensities, their replacement went along with substantial increases of all 'negative' ratings (including fear and disgust) and decreases of happiness and valence ratings for the resulting anger evoking subcategory. So from both competing perspectives, this should have lead to higher startle magnitudes. Two reasons might explain, why this does not appear to show in the data. First, the high 'negative' emotional ratings found for the anger evoking stimuli might reflect some form of higher cognitive processes (e.g. moral judgments) rather than basic emotional reactions. A second possibility is, that, against all expectation, some distinctness of the relevant discrete emotions is a prerequisite to affective startle.

Taken together, if the discrete emotion of anger actually potentiates startle responses, magnitudes for the low-valence category might be somewhat reduced due to the lower validity of the selected anger evoking stimuli. On the other hand, for several reasons it seems generally unfavorable to apply anger evoking pictures to the present context, at least if realized via the IAPS (and by employing Western European students). This shows in the fact that controlling the anger evoking IAPS stimuli for the elicitation of fear and other emotions results in a set of pictures which a-priori were held inappropriate.

The saddening pictures, on the other hand, all seem to relate to the topic of 'loss of a beloved', which should be quite a universal theme. At least for the ones showing more than one person this is most likely the case, suggesting sadness to be elicited as expected. So, the difference in startle magnitudes between the disgusting and the saddening pictures illustrates clearly that not all low-valence stimuli increase the startle reflex equally. The negative finding for the entire low-valence category can not be explained solely by a possible validity problem of the anger evoking stimuli. Rather it seems that within the discrete non-fear low-valence emotions, only disgust bears a substantial relation to the startle reflex.

Some aspects are worth considering for future experiments. First, as long as no culturally adequate norms are available, it seems reasonable to conduct pilot studies to collect discrete emotional rating data for the applied stimuli. In doing so it can be decided more explicitly whether the intended emotional effects are actually achieved. Second, follow-up experiments should apply the same number of stimuli to every discrete emotional category. In the present case comparisons of the various low-valence subcategories with the threat and especially the high-valence category seem statistically not feasible. So it can only be assumed that disgust potentiates startle in a comparable order of magnitude as is the case for fear. Similarly, sadness can only be attributed a tendency to alleviate startle responses, and equal stimulus numbers (and presumably larger sample sizes) seem necessary to decide this issue. Further, it might prove interesting to see, whether the extended threat hypothesis is able to predict, which 'positive' stimuli lead to startle alleviation. At first glance, stimuli conveying some kind of secureness information, or ones simply being incompatible with threat, might be good candidates. Incompatibility should be achieved by involving strong competing behavioral tendencies, which could be triggered by e.g. erotic stimuli, already being shown to alleviate startle [24]. Stimuli conveying secureness might e.g. be scenes depicting parents behaving in a protective manner to their children. Preliminary evidence for the latter prediction can be found in the present experiment for IAPS stimuli 2540 and 3211 showing women embracing a child, which overall effected very low startle magnitudes (m=.616). So the extended threat hypotheses might account for affective alleviation as well as potentiation of the startle response. Finally, although eye EMG is a classical method for assessing the startle response, it might contribute to the validity of the findings to replicate them by means of other measures. Unfortunately, the galvanic skin response (GSR), a physiological parameter which is quite easy to derive, is said to depend on arousal [25]. So assessing startle responses via GSR might lead to results which are not so easy to interpret. EMG of the extremities might be another reliable indicator, but it remains to be seen whether it provides a sensitivity similar to that of the eye muscles.

Concluding, the widespread notion no longer holds that affective startle modulation depends on the valence of the applied foreground stimuli. In contrast, it was shown that the contribution of specific discrete emotions largely determines the eye blink following an acoustic startle probe. Nevertheless, because valence itself depends on discrete emotions typically perceived as 'negative' or 'positive', startle magnitude may easily seem to depend on valence, at least as long as it stems from the discrete emotions of fear and disgust. Whether the significance of discrete emotions can be shown in other fields of experimental psychology, where dimensional emotion concepts are still established, remains to be seen.

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