

Close - but not distant - conditioned flanker emotion affects crowding

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Crowding is affected by conditioned stimulus emotion. This effect is clearly observed for conditioned flankers, but only marginally pronounced for conditioned targets. Studies on the processing of emotional stimuli suggest that the magnitude of the emotional effect depends on the presentation depth in that effects of emotion increase with decreasing distance to the observer in depth. Based on respective findings, we investigate crowding with stimuli of conditioned negative and neutral emotion across real depth; that is, stimuli were either presented closer, at or farther away than the fixation depth. Conditioned emotion of flankers affected crowding when flankers were presented closer than or at fixation depth, which is also the distance the target was presented at. Farther away than the fixation depth, flanker emotion did not alter crowding (Experiment 1a). Conditioned target emotion, however, did only show weak effects on crowding; neither when flankers (Experiment 1b) nor when targets were varied in depth (Experiment 2) there was a clear effect of target emotion, replicating findings in two-dimensional settings. Taken together, the results suggest that flanker's emotional associations can become important for crowding, although, it depends on the special processing characteristics of stimulus emotion in depth. The conditioned emotion of targets scarcely affected crowding.

Introduction

How a visual target stimulus is perceived and processed depends on a variety of factors. Locating a peripheral target close to additional stimuli makes its recognition much more difficult, an effect known as visual crowding (Bouma, 1970; for reviews see Levi, 2008; Pelli & Tillman, 2008; Rosenholtz, 2016; Whitney & Levi, 2011). Crowding decreases with increasing

spacing between target and surrounding flankers until, at a certain target-to-flanker spacing, recognition is restored. This threshold of target-to-flanker distance is commonly referred to as the critical spacing (Levi, 2008). Critical spacing increases monotonically with increasing eccentricity (Bouma, 1970; Huckauf & Heller, 2002; Toet & Levi, 1992). Thus, crowding was shown to largely depend on the eccentricity of stimulus presentation, on the spacing between target and flankers, and on the interaction of these two basic spatial factors (e.g., Bouma, 1970). Not only do basic sensory factors like target eccentricity and target-to-flanker spacing affect processing of a peripherally presented stimulus, but also higher-level factors like stimulus emotion. For example, emotional stimuli were shown to facilitate contrast sensitivity for gratings in the periphery (e.g. Phelps, Ling, & Carrasco, 2006). Although crowding deteriorates stimulus recognition, there is evidence that higher-level associations can be preserved even from crowded stimuli. For example, emotional meaning can survive crowding and elicit priming effects (i.e. Kouider, Berthet, & Faivre, 2011).

There is already a variety of data suggesting a processing bias toward negative compared to neutral stimuli (e.g. Carretié, 2014; Kattner & Clausen, 2020; Yiend, 2010). In addition, there is a growing amount of evidence suggesting that perception and also the emotional processing of stimuli depend on their position in 3D space (Nag, Berman, & Golomb, 2019; Pewan & Rinkenauer, 2020; Van der Stoep, Nijboer, & Van der Stigchel, 2014; Van der Stoep, Serino, Farnè, Di Luca, & Spence, 2016; Yue, Jiang, Li, Wang, & Chen, 2015). Studies using emotional facial expressions showed that accuracy of emotion categorization declines with increasing distance from the observer (e.g. Hager & Ekman, 1979; Smith &

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Schyns, 2009). Furthermore, Gerhardsson, Högman, & Fischer (2015) demonstrated a decline in perceived intensity of emotional facial expressions with increasing viewing distance by manipulating perceived distance via size changes. In addition, reactions to other threatening emotional stimuli were shown to depend on spatial distance. For example, persons with arachnophobia perceive approaching spiders to be faster than low spider-fearful people (e.g. Basanovic, Dean, Riskind, & MacLeod, 2019). In addition, Mühlberger, Neumann, Wieser, and Pauli (2008) investigated emotional reactions toward pleasant, unpleasant, and neutral stimuli, which were perceived as approaching or receding by dynamically changing size. Their results showed that approaching unpleasant stimuli, but not pleasant or neutral stimuli, elicit stronger emotional reactions. Taken together, all these studies suggest an increased impact of emotional stimuli when stimuli are presented at close distance to the observer. In other words, one might assume that effects of emotional content of a stimulus might be underestimated when studying at a constant distance, that is, on a two-dimensional surface. This seems of special importance, because most of the visual information which we encounter in natural vision is distributed across the three-dimensional (3D) space.

However, studying the impact of emotions on perceptual phenomena like crowding may not be trivial. Emotional stimuli were shown to not only differ from neutral stimuli regarding affective factors, but also regarding perceptual factors (Delplanque, N'diaye, Scherer, & Grandjean, 2007; Horstmann, Borgstedt, & Heumann, 2006; Lakens, Fockenberg, Lemmens, Ham, & Midden, 2013). One method to examine emotional effects while controlling for possible sensorial confounds consist in the evaluative conditioning (EC) paradigm (e.g. Kliegl, Watrin, & Huckauf, 2015; Pittino, Eberhardt, Kurz, & Huckauf, 2019; Pittino, Kliegl, & Huckauf, 2017). In EC, the liking of a conditioned stimulus (CS) is changed by repeatedly pairing the originally neutral stimulus (NS) with affective unconditioned stimuli (UCS; De Houwer, Thomas, & Baeyens, 2001). Previous studies suggest that evaluatively conditioned stimuli elicit similar effects as primarily emotional stimuli, that is, changes in subjective, physiological, and behavioral responses (Dawson, Rissling, Schell, & Wilcox, 2007; De Houwer et al., 2001; Hofmann, De Houwer, Perugini, Baeyens, & Combez, 2010; Kliegl, Watrin et al., 2015; Notebaert, Crombez, van Damme, De Houwer, & Theeuwes, 2011; Pittino et al., 2017; Pittino et al., 2019).

In a recent study, Pittino et al. (2019) used EC to examine effects of emotion on crowding. Pittino et al. (2019) paired Landolt rings with opposing gap positions either with negative or with neutral pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008; UCS). Afterward, negative and neutral CS were used as targets and flankers in a

visual crowding paradigm. When using these negatively and neutrally conditioned rings as flankers, larger critical spacings for negative compared to neutral flankers were observed (Pittino et al., 2019). That is, conditioned stimulus emotion of flankers altered crowding effects. For conditioned target emotion, only relatively weak effects were observed: Only for a subset of participants who showed strong evaluative conditioning effects, crowding with negative targets was reduced compared to neutral targets (Pittino et al., 2019).

In sum, by using the method of EC, it was shown that crowding effects are modulated by emotion associated with flankers. Thus, flankers associated with negative emotion seem to gain a processing priority, which fits well with the assumption of a processing bias for emotional stimuli (e.g. Carretié, 2014; Kattner & Clausen, 2020; Yiend, 2010). But, when using them as targets, interference from flankers remained largely unaffected. Thus, it seems as if conditioned emotion of flankers affects crowding, but conditioned emotion of targets has only a limited effect. This result may suggest that emotion information does not easily survive crowding. Taking into account the above reviewed studies showing that effects of stimulus emotion depend on presentation depth, one might wonder whether effects of stimulus emotion on crowding are underestimated due to the constant presentation distance.

For crowding effects at issue, one might thus assume that the impact of emotional stimuli on crowding depends on the distance to the observer: for flankers, one might assume that the increase of crowding for negative compared to neutral flankers is more pronounced for close than for far presentations. For targets, the reduction of crowding effects for negative compared to neutral targets might be more pronounced for targets close to the observer relative to far targets.

With regard to distance, there have already been studies on crowding reported by Eberhardt and Huckauf (2020). They investigated crowding effects when either targets or flankers were varied in real depth, avoiding perceptual detriments of virtual depth techniques (Hoffman, Grishick, Akeley, & Banks, 2008; Kim, Kane, & Banks, 2014; Lambooi, Ijsselstein, & Heynderickx, 2007). For varying stimuli in real depth, crowding was altered in an observer-centered manner: whenever targets were presented close to the observer (i.e. in front of the fixation plane while flankers were at the fixation plane), crowding was stronger than for targets presented behind the fixation plane. When varying flankers in real depth while keeping targets on the fixation plane, the flankers close to the observer produced less crowding compared to flankers farther away.

To sum up, it had been demonstrated that emotion affects crowding, and that respective effects are larger

for emotional flankers than for emotional targets. Both emotion and crowding effects are affected by the distance of the stimuli to the observer. This poses the question in which way crowding across depth is modulated by stimulus emotion. The present study addresses this question by varying the emotion of flankers (Experiment 1a) and targets (Experiment 1b and Experiment 2), and the depth of flankers (Experiment 1) and of targets (Experiment 2) to examine the joint effects of emotion and depth on crowding.

In order to investigate how negative compared to neutral stimuli affect crowding across depth, in the present study, Landolt rings were evaluatively conditioned and presented as defocused targets or flankers. We investigated conditioned emotion of stimuli, defined by the dimensions of valence and arousal (Russell, 1980) presented in a crowding setting in real 3D. In Experiment 1, flankers were defocused, that is, flankers were presented either closer, at, or farther away than the fixation depth. As the results will show, conditioned emotion of flankers affects crowding only when flankers are presented closer than, or at fixation depth (Experiment 1a). Conditioned target emotion, however, did not show any effect on crowding (Experiment 1b). Investigating the depth of conditioned targets in Experiment 2 showed that target emotion for targets presented in depth did as well only as the result in a marginal effect on crowding.

Experiment 1

In Experiment 1, we investigated the effect of stimulus emotion on crowding when flankers were varied in depth, and either flanker emotion (Experiment 1a) or target emotion (Experiment 1b) were evaluatively conditioned.

In Experiment 1a, we investigated how flanker emotion affects crowding when flankers are defocused in real depth. Therefore, negatively or neutrally conditioned flankers were presented either closer, at, or farther away the fixation depth, on which not-conditioned targets were presented. We expected that negative compared to neutral flankers increase crowding, as shown in Pittino et al. (2019) in 2D, but that this effect is more pronounced for flankers close to compared to far from the observer, as studies on emotional processing in depth suggest (e.g. Mühlberger et al., 2008).

In Experiment 1b, targets were evaluatively conditioned. Already in 2D, target emotion only produced marginal effects on crowding (Pittino et al., 2019). But, if an effect of target emotion occurs across depth, we would expect reduced crowding for negatively compared to neutrally conditioned targets, again more

pronounced for close compared to far targets from the observer.

Methods

Participants

The sample consisted of 24 right-handed participants (19 women; $M_{age} = 22$ years; $SD = 2$) with normal or corrected-to-normal vision, which was evaluated by a binocular visual acuity test ($Med = 1.25$, $Min = 1.00$, and $Max = 1.25$). Stereovision was tested by the TNO Stereo Vision Test ($Med = 60$ arcmin, $Min = 240$ arcmin, and $Max = 30$ arcmin). All participants signed a written consent form prior to testing and could get partial course credit for participation. The experiment was conducted in line with the Declaration of Helsinki.

Apparatus

Two 26-inch NEC MultiSync LCD screens (resolution 1440×900 px; refresh rate 60 Hz) were used. Simultaneous stimulus presentation was controlled by MATLAB (version 7.9) and Psychtoolbox (version 3; Brainard, 1997; Pelli, 1997), running on a Windows XP operating system with a Matrox M9138 LP graphics device. Luminance at the participant's eye position was approximately 2.8 lx. The experimental setup is shown in Figure 1. The two screens were positioned orthogonally to each other, both were adjustable in distance along a rail. A semitransparent mirror was mounted in a 45 degree angle at the point of intersection of the rails. Stimuli presented on screen 2 were reflected by the semitransparent mirror in the gaze direction of the participant. Thus, two depth planes could be presented simultaneously. Screen 2 was hidden by a movable wall and the head of the participant was fixed by a chin rest.

All stimuli were presented on a dark background (0.2 cd/m^2). Fixation distance was always at 190 cm. For stimulus rating and evaluative conditioning, screen 1 was used. For the crowding task, there were two possible screen configurations. Either screen 1 displayed the fixation depth while the other screen displayed the defocused depths, or vice versa.

Stimulus material

Evaluative conditioning

For valence and arousal ratings, the Self-Assessment Manikin scale (SAM) scale was administered (Bradley & Lang, 1994). As in previous studies (Kliegl, Watrin et al., 2015; Pittino et al., 2017, Pittino et al., 2019), UCS consisted of an individual selection out of 20 neutral

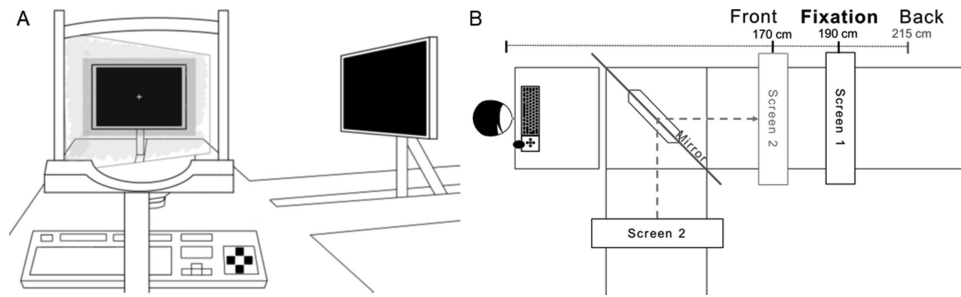


Figure 1. (A) Drawing of the experimental setup to display real depth. (B) Top view of the experimental setup. Screen 2 is reflected by the semitransparent mirror. Both screens are adjustable in distance along a rail. When they are positioned in different distances relative to the semi-transparent mirror, real depth differences between the two depth planes can be presented, as shown in the illustration.

and 20 negative pictures of the IAPS (Lang et al., 2008). The pictures were presented with a size of 12 degrees \times 9 degrees. Bright Landolt rings (white, 160 cd/m²) with a size of 0.6 degrees with opening directions upward, downward, leftward, or rightward were used as CS. For negative and neutral EC, Landolt rings with opposing gap positions were chosen (e.g. if the ring with the opening to the right was conditioned negatively, the ring with the opposite opening direction to the left was conditioned neutrally). The two remaining opening directions were not conditioned. The opening direction of the conditioned rings was balanced across participants.

Crowding task

All stimuli and the fixation cross were bright (white, 160 cd/m²) and sized to 0.6 degrees of visual angle in all depth conditions. The central fixation cross was presented in a viewing distance of 190 cm. Landolt rings with opening directions upward, downward, leftward, or rightward were used as stimuli in the crowding task. The flanker rings were either presented closer to the observer (150 cm), at fixation depth (190 cm), or farther away from the observer (240 cm), always on the not-fixation screen, to the left and right side of the target with a center-to-center spacing of 1 degree. Flankers were identical on each individual trial. Targets were always presented on the fixation screen in a distance of 190 cm with an eccentricity of 1 degree. Relative distances between fixation and defocused depths accounted for approximately ± 0.1 dpt.

Design

The crowding task consisted of six blocks, based on three flanker depths (close, fixation, and far) and the two screen configurations. Block order and conditioned ring opening was permuted between participants. Figure 2 illustrates the experimental design exemplarily for

a certain emotional conditioning condition (specified in Figure 2A). For flanked target presentations, either both flankers consisted of the same conditioned ring (presented together with a not-conditioned target; Experiment 1a, shown in Figure 2B), or the target was a conditioned ring (presented with the same not-conditioned flankers; Experiment 1b, shown in Figure 2C). For each, Experiment 1a and Experiment 1b, two conditioned emotions (neutral and negative), two opening directions of the not-conditioned rings (either left, right, or up, down), and two visual field conditions (left and right) were repeated five times per block, resulting in 80 trials. In addition, all four isolated target rings were presented twice in each visual field per block adding up to 96 trials per block.

Procedure

Overview

The whole experiment took about 75 minutes. First, participants underwent the screening of visual acuity and stereovision. Thereafter, they evaluated valence and arousal of the Landolt rings and the set of pictures of the IAPS (UCS; Lang et al., 2008) using the SAM scale (Bradley & Lang, 1994). Then, the Landolt rings were repeatedly paired with neutral and negative IAPS pictures. After EC, the not-conditioned and conditioned Landolt rings (CS) were rated again regarding valence and arousal using the SAM scale. Then, participants completed the six blocks of the crowding task with 96 trials each. Before each new block, EC was repeated and after the final block, participants again rated Landolt rings regarding valence and arousal. These parts of the experiment are now described in detail.

Stimulus rating

Stimuli for EC were chosen individually, based on subjective ratings of the set of 20 neutral and negative IAPS pictures. Hence, to give participants an overview

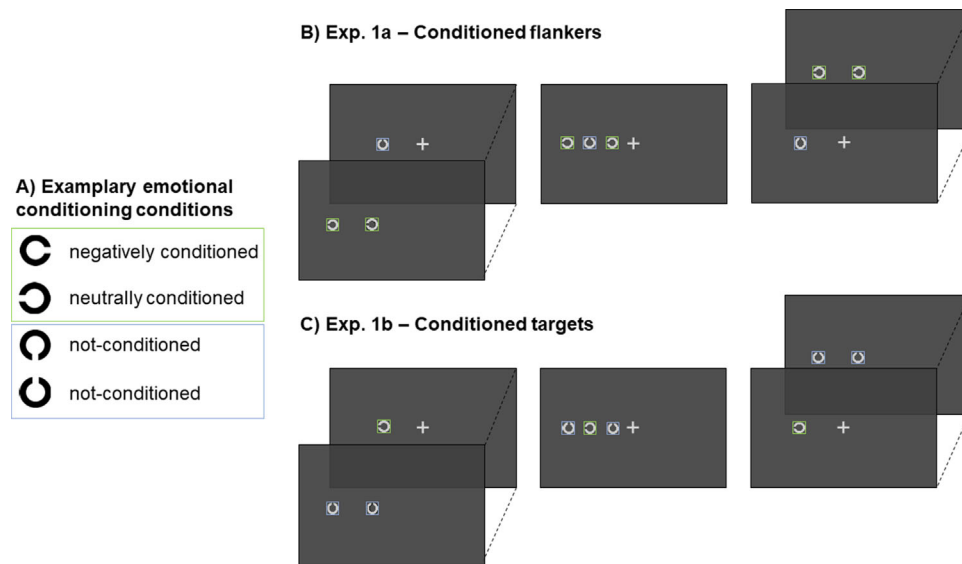


Figure 2. Illustration of experimental conditions in [Experiment 1](#) with flankers varying in depth. **(A)** Conditioned ring openings which are used exemplarily for the present illustration. **(B)** Conditions of [Experiment 1a](#) in which conditioned Landolt rings were used as flankers. **(C)** Conditions of [Experiment 1b](#) in which conditioned Landolt rings were used as targets. Colored frames are only used for the purpose of the present illustration.

of the to-be-rated IAPS pictures (UCS; [Lang et al., 2008](#)), the 20 negative and 20 neutral stimuli were presented in a 4×5 matrix for 7 seconds each before the rating ([Kliegl, Watrin, et al., 2015](#); [Pittino et al., 2017](#), [Pittino et al., 2019](#)). Then, the pictures (UCS) and the four Landolt rings (NS) were presented for 3000 ms in randomized order. After stimulus presentation, participants rated valence and arousal evoked by each stimulus using the SAM scale ([Bradley & Lang, 1994](#)). Based on these ratings an algorithm chose five pictures as neutral UCS and five pictures as negative UCS, according to previous studies ([Kliegl, Watrin et al., 2015](#); [Pittino et al., 2017](#); [Pittino et al., 2019](#)): among the neutrally rated pictures (valence ratings between 4 and 6) the five with the lowest arousal ratings were chosen as the neutral UCS; among the negatively rated pictures (valence ratings smaller than 4) the ones with the highest arousal ratings were chosen as negative UCS. The rating of the four Landolt rings was repeated after the initial EC procedure and at the end of the experiment.

Evaluative conditioning

EC was performed as in previous studies ([Kliegl, Watrin et al., 2015](#); [Pittino et al., 2017](#); [Pittino et al., 2019](#)). Participants fixated a central square ($M_{duration} = 1000$ ms, $SD = 500$ ms) until the to-be-conditioned Landolt Ring (CS) appeared for 1000 ms, followed by the respective picture (UCS) for 3000 ms. In the inter-trial-interval of $M = 1000$ ms ($SD = 500$ ms), an

empty black screen was presented. In the initial EC, each Landolt Ring was paired three times with the respective UCS, resulting in 15 pairings for each CS. As mentioned above, the crowding task was interrupted for short repetitions of EC. The procedure was identical to the initial EC phase, except that each ring was paired only once with each of the five UCS.

Crowding task

In [Experiment 1](#), recognition performance with a fixed target-to-flanker spacing was measured as dependent variable (similar to [Eberhardt & Huckauf, 2017](#); [Eberhardt & Huckauf, 2019](#), [Eberhardt & Huckauf, 2020](#)). Each trial started self-paced with the presentation of a bright fixation cross. After $M = 500$ ms ($SD = 50$ ms) an isolated or flanked target appeared for 20 ms. Participants had to indicate the opening direction of the target ring by keypress within 1000 ms after stimulus presentation.

Results

Manipulation check

A repeated measures ANOVA with the within-subject factors conditioned emotion (neutral versus negative) and moment of measurement (before versus after conditioning versus after crowding task) was conducted

on ratings of valence and arousal, respectively. For valence ratings, results revealed significant main effects of conditioned emotion, $F(1,23) = 43.79$, $p < 0.01$, $\eta_p^2 = 0.66$, and moment, $F(2,46) = 5.51$, $p = 0.01$, $\eta_p^2 = 0.19$. Furthermore, the interaction of conditioned emotion and moment was significant, $F(2,46) = 13.54$, $p < 0.01$, $\eta_p^2 = 0.37$. Post hoc pairwise comparisons indicated that valence of negative and neutral rings did not differ before conditioning, $\Delta M = -0.04$, $SE = 0.13$, $p = 0.75$. However, negative rings were rated to be more negative than neutral rings after conditioning, $\Delta M = -1.25$, $SE = 0.28$, $p < 0.01$, and after the crowding task, $\Delta M = -1.79$, $SE = 0.31$, $p < 0.01$.

For arousal ratings there were significant main effects of conditioned emotion, $F(1,23) = 28.92$, $p < 0.01$, $\eta_p^2 = 0.56$, and moment, $F(2,46) = 15.61$, $p < 0.01$, $\eta_p^2 = 0.40$. Furthermore, the interaction of conditioned emotion and moment was significant, $F(2,46) = 14.30$, $p < 0.01$, $\eta_p^2 = 0.38$. Post hoc pairwise comparisons indicated that arousal ratings did not differ before conditioning, $\Delta M = -0.04$, $SE = 0.04$, $p = 0.33$. However, negative rings were rated with higher arousal than neutral rings after conditioning, $\Delta M = 2.16$, $SE = 0.47$, $p < 0.01$, and after the crowding task, $\Delta M = 2.04$, $SE = 0.44$, $p < 0.01$. Thus, replicating previous work, the liking of the conditioned stimuli was successfully changed (De Houwer et al., 2001; Hofmann et al., 2010; Kliegl, Watrin, et al., 2015; Pittino et al., 2017; Pittino et al., 2019).

Experiment 1a: Crowding effects for conditioned flanker emotion

Recognition performance for isolated targets was with $M = 95.40\%$ ($SE = 1.41$) substantially higher than for flanked conditions (all p values < 0.01), confirming the occurrence of crowding.

Figure 3 shows the crowding effects, as calculated by subtracting flanked from isolated recognition performance, as a function of flanker depth and flanker emotion. To test whether crowding effects in the investigated depths were modulated by flanker emotion a repeated measures ANOVA with the within-subject factors conditioned emotion (neutral versus negative) and flanker depth (close versus fixation versus far) was conducted. The results revealed a significant main effect of flanker depth, $F(1.61,46) = 13.82$, $p < 0.01$, $\eta_p^2 = 0.38$. Post hoc conducted pairwise comparisons revealed more crowding for flankers presented far, compared to the fixation depth, $\Delta M = -8\%$, $SE = 1.8$, $p < 0.01$, or close to the observer, $\Delta M = -12.2\%$, $SE = 2.8$, $p < 0.01$. The main effect of flanker emotion was significant only by trend, $F(1,23) = 3.68$, $p = 0.07$, $\eta_p^2 = 0.14$. Furthermore, the interaction of flanker depth and flanker emotion was significant, $F(2,46) = 6.96$,

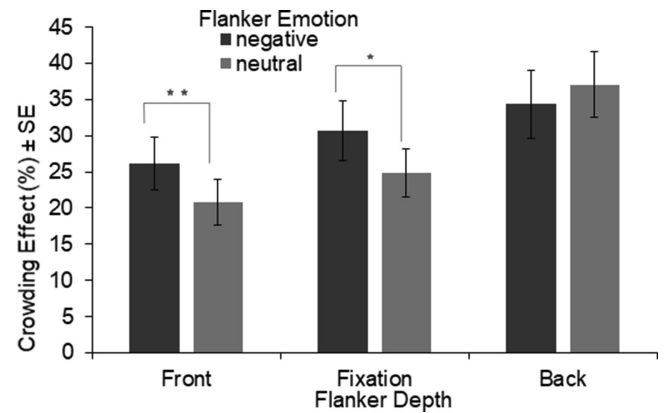


Figure 3. Crowding effects (i.e. differences in recognition performances between isolated and flanked target presentation) for conditioned flankers as a function of flanker depth and flanker emotion. ** Refers to $p < 0.01$, * refers to $p < 0.05$.

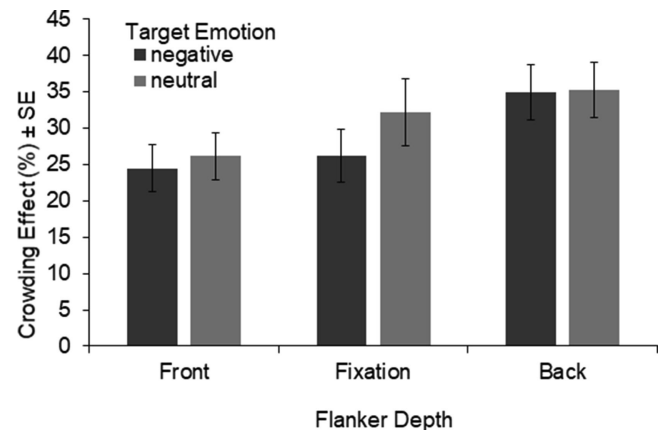


Figure 4. Crowding effects for conditioned targets as a function of flanker depth and target emotion.

$p < 0.01$, $\eta_p^2 = 0.23$. Post hoc comparisons showed that negative compared to neutral flankers produced significantly more crowding when flankers were at the fixation depth, $\Delta M = -5.7\%$, $SE = 2.2$, $p = 0.02$, and when flankers were close, $\Delta M = -5.3\%$, $SE = 1.8$, $p < 0.01$, but not when flankers were far from the observer, $\Delta M = 2.7\%$, $SE = 2.1$, $p = 0.22$.

Experiment 1b: Crowding effects for conditioned target emotion

Recognition performance for isolated targets did not differ between negatively conditioned targets ($M_{neg} = 96.01\%$, $SE = 1.34$) and neutrally conditioned targets ($M_{neu} = 93.23\%$, $SE = 1.92$, $t(23) = 1.48$, $p = 0.15$). Figure 4 shows crowding effects for conditioned targets as a function of flanker depth and target

emotion. To test whether crowding effects in the investigated depths were modulated by target emotion, a repeated measures ANOVA with the within-subject factors conditioned target emotion and flanker depth was conducted. The results revealed a main effect of flanker depth, $F(2,46) = 7.47$, $p < 0.01$, $\eta_p^2 = 0.25$. Post hoc conducted pairwise comparisons showed that crowding was significantly increased when flankers were far compared to on the fixation depth, $\Delta M = -6\%$, $SE = 2.3$, $p = 0.046$, or close, $\Delta M = -9.8\%$, $SE = 2.3$, $p < 0.01$. The main effect of target emotion and the interaction of flanker depth and target emotion were not significant, $F(1,23) = 1.12$, $p = 0.30$, and $F(2,46) = 2.18$, $p = 0.13$, respectively.

Discussion

In [Experiment 1](#), we investigated how processing of a target stimulus is affected when flanking stimuli deviate in depth and either flanker or target stimuli are evaluatively conditioned with negative or neutral emotion. The manipulation check regarding EC replicates the findings of previous studies ([De Houwer et al., 2001](#); [Hofmann et al., 2010](#); [Kliegl, Watrin et al., 2015](#); [Pittino et al., 2017](#); [Pittino et al., 2019](#)), showing strong evaluative conditioning effects: prior to EC neither valence, nor arousal ratings of negative and neutral CSs differed. After conditioning, however, negative rings were rated to be more negative and more arousing than neutral rings. This pattern was still observable at the end of the experiment.

In addition, the effect of depth on crowding was replicated: in both, [Experiment 1a](#) and [Experiment 1b](#), the results revealed an effect of flanker depth: crowding was reduced when flankers were presented at fixation or in front of it (i.e. closer to the observer, compared to farther away). This effect of real flanker depth replicates observer-centered result patterns of previous experiments reported by [Eberhardt and Huckauf \(2020\)](#). Further, effects of emotion on crowding were replicated: in [Experiment 1a](#), it was investigated whether the amplifying effect of negative compared to neutral conditioned flanker emotion described by [Pittino et al. \(2019\)](#) occurs also when flankers are defocused in depth. Crowding was significantly reduced for negative compared to neutral flankers close to the observer, as well as on the fixation depth, but not with flankers farther away. This replicates the effect of [Pittino et al. \(2019\)](#) and extends it to indicate that it is sensitive to observer-centered distance (i.e. egocentric distance).

The interaction of flanker depth and flanker emotion also shows that flankers producing a relatively weak crowding effect – which are those presented on the fixated depth or close to the observer – interact with target recognition depending on their emotion. But, the

emotion of those flankers producing a rather strong crowding effect (i.e. flankers presented behind the fixated depth) did not impact the crowding effect. This points in fact toward an interaction of emotion effects with presentation depth.

In [Experiment 1b](#), target emotion was conditioned. The results indicate that crowding did not depend on conditioned target emotion, again replicating the findings of [Pittino et al. \(2019\)](#) who could also not show an alleviating effect of negative target emotion for the analysis comprising the entire sample, but only in a post hoc analysis of those observers showing strong conditioning effects. Thus, EC produces additional effects of flankers, but not of targets, in a crowding setting.

Experiment 2

In [Experiment 1](#), targets were always presented at fixation depth. Hence, before concluding that conditioned target emotion does not affect crowding in real 3D, targets were to be presented at various distances, because presentation distance might be an important covariate for the effect of emotion to occur (e.g. [Basanovic et al., 2019](#); [Gerhardsson, Högman, & Fischer, 2015](#); [Hager & Ekman, 1979](#); [Mühlberger et al., 2008](#); [Smith & Schyns, 2009](#)). Therefore, in [Experiment 2](#), negatively or neutrally conditioned targets were presented either close to the observer or farther away than the fixation depth, on which not-conditioned flankers were presented. [Eberhardt and Huckauf \(2020\)](#) showed that defocused targets are more affected by crowding when they are presented close compared to farther away from the observer. Thus, we expected larger critical spacings for close compared to far targets. Furthermore, we explored the effect of conditioned target emotion. In case that target emotion is able to modulate crowding across depth, we would expect, based on the results of [Pittino et al. \(2019\)](#), smaller critical spacing for negatively compared to neutrally conditioned targets. Further, one might expect that this effect occurs in an observer-centered manner, that is, stronger effects of target emotion for close compared to far targets.

Methods

Participants

The sample consisted of 38 participants with normal or corrected-to-normal vision and appropriate stereovision. Due to outliers in the critical spacings only the data of 32 participants (27 female; $M_{age} = 23$

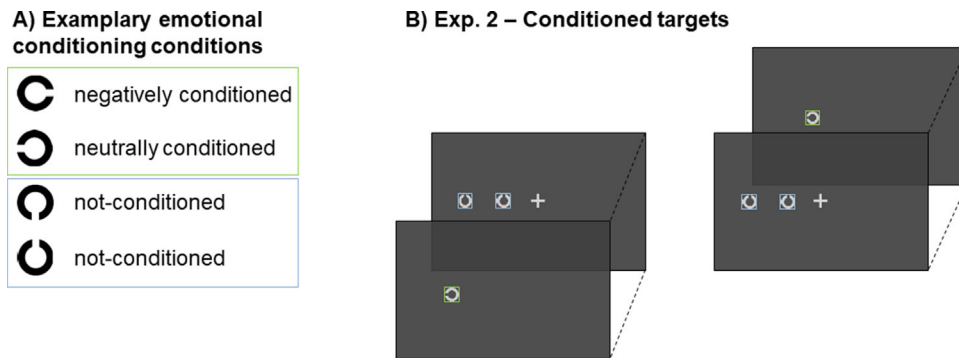


Figure 5. Illustration of experimental conditions in [Experiment 2](#) with targets varying in depth. **(A)** Conditioned ring openings, which are used exemplarily for the present illustration. **(B)** Conditions of [Experiment 2](#) in which conditioned Landolt rings were used as targets. Colored frames are only used for the purpose of the present illustration.

years; $SD = 4$) were analyzed. Visual acuity was tested binocularly ($Med = 1.25$, $Min = 1.0$, and $Max = 1.25$) and monocularly for both eyes (left: $Med = 1.25$, $Min = 0.4$, and $Max = 1.25$; right: $Med = 1.25$, $Min = 0.6$, and $Max = 1.25$). Stereovision was tested by the TNO Stereo Vision Test ($Med = 60$ arcmin, $Min = 480$ arcmin, and $Max = 30$ arcmin). Prior to the Experiment all participants signed a written consent form. Partial course credits could be earned for participation. The experiment was conducted in line with the Declaration of Helsinki.

Apparatus, stimulus material, and design

Apparatus, stimulus material for ratings, and EC was identical to [Experiment 1](#). Stimulus characteristics for the crowding task were similar to [Experiment 1](#), except for the following: the target ring was either presented in front of (150 cm) or behind (240 cm) the fixation depth, always on the non-fixation screen, with a horizontal eccentricity of 3 degrees. Flankers, presented always on the fixation screen in a distance of 190 cm, were positioned on the left and right side of the target, with adaptively varied spacing. Distances between fixation and defocused depths accounted for ± 0.1 dpt. [Figure 5](#) illustrates the experimental design exemplarily for a certain emotional conditioning condition (specified in [Figure 2A](#)).

The crowding task consisted of four blocks, based on the two target depths (front and behind) and the two screen configurations. Between participants, block order and the conditioned ring openings were permuted. Each block consisted of 160 trials, given by 20 repetitions of two conditioned target emotions (neutral and negative), two remaining possibilities for the flankers opening direction, and two visual fields (left and right).

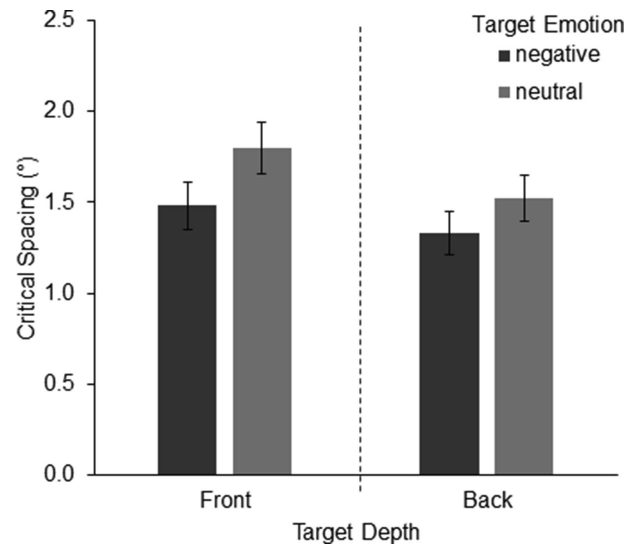


Figure 6. Means and standard errors of critical spacing in degrees of visual angles as a function of target depth and conditioned target emotion.

Procedure

The course of the experiment was similar to the procedure of [Experiment 1](#), despite that the crowding task in [Experiment 2](#) was done in four blocks only. Each experimental block was interrupted halfway through for a short relaxation break. Each trial started self-paced with the presentation of a bright fixation cross. After $M = 500$ ms ($SD = 50$ ms) the flanked target appeared for 80 ms. Participants had to indicate the opening direction of the target ring by keypress within 1000 ms after stimulus presentation. As a dependent variable, critical spacing was measured individually for each participant and each experimental condition. Critical spacing was defined as the 75% threshold for target recognition. In each experimental

block, spacing was controlled by the adaptive Bayesian QUEST function individually for the negative and neutral target condition (Watson & Pelli, 1983). The initial slope parameter β was set to 3.5 degrees⁻¹ and the guessing rate was set to the chance-level of 50%. Based on stimulus size and eccentricity the spacing was restricted to vary between 1 degree and 2.5 degrees.

Results

Data analysis

Data were analyzed using IBM SPSS Statistics (version 24). Prior to inferential analyses, outlier analysis was performed for critical spacings as a function of target depth and target emotion by using box plots (Tukey, 1997). Thus, the data of six participants was excluded because of outliers in at least one condition (critical spacing outside the range of median \pm 3* interquartile range).

Manipulation check

To check the effectiveness of the evaluative conditioning procedure a 2 \times 3 repeated measures ANOVA with the within-subject factors conditioned emotion (negative versus neutral) and moment of measurement (before versus after conditioning versus after crowding task) was conducted on ratings of valence and arousal. For valence ratings, the analysis revealed significant main effects of conditioned emotion, $F(1,31) = 37.17$, $p < 0.01$, $\eta_p^2 = 0.55$, and moment, $F(2,62) = 5.31$, $p < 0.01$, $\eta_p^2 = 0.15$, and an interaction of emotion and moment, $F(2,62) = 19.48$, $p < 0.01$, $\eta_p^2 = 0.37$. Post hoc pairwise comparisons indicated that valence of negative and neutral rings did not differ before conditioning, $\Delta M = 0.06$, $SE = 0.1$, $p = 0.54$. However, negative rings were rated to be more negative than neutral rings after conditioning, $\Delta M = -1.84$, $SE = 0.33$, $p < 0.01$, and after the crowding task, $\Delta M = -1.53$, $SE = 0.29$, $p < 0.01$, thus demonstrating a clear effect of evaluative conditioning (De Houwer et al., 2001; Hofmann et al., 2010; Kliegl, Limbrecht-Ecklundt, Dürr, Traue, & Huckauf, 2015; Pittino et al., 2017; Pittino et al., 2019).

For arousal ratings there were significant main effects of conditioned emotion, $F(1,31) = 34.66$, $p < 0.01$, $\eta_p^2 = 0.53$, and moment, $F(2,62) = 33.83$, $p < 0.01$, $\eta_p^2 = 0.52$. Furthermore, the interaction of emotion and moment was significant, $F(2,62) = 32.73$, $p < 0.01$, $\eta_p^2 = 0.51$. Again, as for valence, post hoc pairwise comparisons indicated that arousal ratings did not differ before conditioning, $\Delta M = -0.16$, $SE = 0.16$, $p = 0.34$. However, negative conditioned rings were

rated to be more arousing than neutral rings after conditioning, $\Delta M = 3.25$, $SE = 0.48$, $p < 0.01$, and after the crowding task, $\Delta M = 2.25$, $SE = 0.45$, $p < 0.01$. Thus, replicating previous work, the liking of the conditioned stimuli was successfully changed (De Houwer et al., 2001; Hofmann et al., 2010; Kliegl et al., 2015; Pittino et al., 2017; Pittino et al., 2019).

Crowding effects

Critical spacing was analyzed as a function of target depth (close versus far) and conditioned target emotion (negative versus neutral). Mean values and standard errors are plotted in Figure 6. To test whether crowding effects across depth were modulated by target emotion, a repeated measures ANOVA with the within-subjects factors target depth and target emotion was conducted on critical spacing data. The results revealed a main effect of target depth, $F(1,31) = 13.46$, $p < 0.01$, $\eta_p^2 = 0.30$, indicating larger critical spacings for close compared to far target depth. Further, a marginally significant main effects of target emotion was observed, $F(1,31) = 3.63$, $p = 0.07$, $\eta_p^2 = 0.11$, with larger critical spacing for neutrally compared to negatively conditioned targets. There was no interaction of target depth and target emotion, $F(1,31) = 1.58$, $p = 0.22$, $\eta_p^2 = 0.05$.

Discussion

The aim of Experiment 2 was to investigate whether conditioned target emotion affects crowding when the neutrally or negatively conditioned target stimulus is presented in depth (i.e. closer or farther away than the observer's fixation depth where flanker stimuli are presented). Again, the manipulation check using valence and arousal ratings revealed a successful evaluative conditioning effect. Nevertheless, again, for targets, only weak emotion effects on crowding were observed. This replicates findings of Pittino et al. (2019) in 2D as well as findings of Experiment 1b using another spatial configuration and another dependent variable. Hence, despite various attempts it seems as if target emotion does scarcely survive crowding.

The results also replicate the effect of real target depth reported by Eberhardt and Huckauf (2020), irrespective of target emotion: stronger crowding effects were observed for targets closer compared to farther away than the fixation depth, as indicated by larger critical spacings.

Taken together, conditioned target emotion produces relatively small effect sizes, independent of the target's position in depth. Nevertheless, the

effect of target depth was clearly pronounced; that is, crowding effects were stronger for targets closer to the observer and weaker behind the fixated distance.

General discussion

The aim of the present study was to investigate how conditioned stimulus emotion affects crowding across depth. To this end, either flankers ([Experiment 1](#)) or targets ([Experiment 2](#)) were defocused in depth, whereas neutrally and negatively conditioned stimuli were used as flankers ([Experiment 1a](#)) or as targets ([Experiment 1b](#) and [Experiment 2](#)). As in previous studies ([Kliegl, Watrin et al., 2015](#); [Pittino et al., 2017](#), [Pittino et al., 2019](#)), Landolt rings with opposing gap positions were, therefore, evaluatively conditioned with negative and neutral IAPS pictures ([Lang et al., 2008](#)).

In both experiments, the manipulation check regarding EC replicated the findings of previous studies (e.g., [Kliegl, Watrin, et al., 2015](#); [Pittino et al., 2017](#); [Pittino et al., 2019](#)), showing strong evaluative conditioning effects: after conditioning, negative rings were rated to be more negative and more arousing than neutral rings, although prior to EC, neither valence nor arousal ratings of negative and neutral CSs differed. An EC effect was still observable at the end of the experiment; thus, as an aside, speaking in favor of a resistance of EC to extinction (e.g. [Baeyens, Díaz, & Ruiz, 2005](#); [De Houwer et al., 2001](#); [Hofmann et al., 2010](#)).

The present study replicates and significantly extends the findings of [Pittino et al. \(2019\)](#) regarding the effect of conditioned flanker emotion on crowding: the conditioned emotion of flankers altered crowding effects – but only if the flankers were presented relatively close to the observer (closer than or at fixation depth). We did not observe an effect of conditioned emotion on crowding for flankers presented farther away than the fixation depth. Previous studies on emotional processing of stimuli in depth suggest that emotional processing of close stimuli is enhanced compared to more distant stimuli (e.g. [Mühlberger et al., 2008](#)). However, none of these studies investigated the role of the observer's current fixation position in depth. [Experiment 1a](#) suggests that the observer's fixation depth might act as a reference for emotional processing in depth, framing the space into close areas and distant areas. Given findings showing that relevant stimuli elicit stronger emotional responses ([Codispoti & de Cesarei, 2007](#); [de Cesarei & Codispoti, 2008](#); [Kliegl, Limbrecht-Ecklundt, Dürr, Traue, & Huckauf, 2015](#)), one might speculate that close and distant areas modulate stimuli's relevance to the observer. With regard to action tendencies, it seems

plausible to assume that stimuli close to the observer are of increased relevance for direct interaction with the environment and thus are processed prioritized eliciting enhanced behavioral outcomes.

For the crowding effects at issue, the current findings show that interactions between target and flankers resulting in crowding are shaped by distance from the observer. Replicating previous findings ([Eberhardt & Huckauf, 2020](#)) crowding effects were significantly stronger (1) when flankers were presented farther away than closer from the fixation depth, and (2) when targets were presented closer compared to farther away from the fixation depth. The fact that differences in depth between closer than versus farther away from fixation depth do not affect crowding effects symmetrically shows that early level sensory processing cannot solely be responsible for such depth effects. This is also strengthened by the fact that in close and far distance, all stimuli were presented clearly within the depth of field (e.g. [Campbell, 1957](#)), even symmetrically in terms of diopters, and thus, must be assumed to have produced a sufficiently sharp image on the retina (see also [Eberhardt & Huckauf, 2020](#)). Hence, also crowding effects must be assumed to reflect effects of observing distance: the observer's fixation depth might act as a reference for crowding in depth, probably framing the space into observer-relevant close areas, and observer-irrelevant distant areas. Interestingly, when flankers are presented in relatively close areas, crowding effects are smaller than in observer-irrelevant distant areas.

This is especially of interest, because some specific crowding effects in 3D - that are spatial interactions between a target displayed at fixation distance and flankers displayed there as well, or in closer or farther distance - were modulated by the flanker's emotion. This finding suggests that higher-level spatial information (i.e. depth, has already been processed before the conditioned emotion of the flankers comes into play). Taken together, the current findings suggest that crowding effects in 3D are at least partly generated during rather late processing of spatial information during which interpretations of relevant close and irrelevant far areas have already been performed. The results of the present study are also highly interesting from a theoretical perspective. The data show an effect of higher-level information (conditioned stimulus emotion) on crowding. This finding can hardly be explained by models explaining crowding solely by low-level visual processing (e.g. [Greenwood, Bex, & Dakin, 2009](#); [Rosenholtz, Yu, & Keshvari, 2019](#)). Thus, our data are more in line with models assuming that target-flanker interference can occur at various levels of visual processing reaching up to higher-level processing of stimulus meaning, such as conditioned stimulus emotion (e.g. [Manassi & Whitney, 2018](#); [Whitney & Levi, 2011](#)).

Interestingly, strong crowding effects with defocused flankers (presented farther away than the fixation depth) went along with zero effects of conditioned flanker emotion. That is, the fact that flankers have a huge impact on target recognition does not imply that flankers are processed until higher-level features, like their emotional meaning, is unfolded. On the contrary, such higher-level flanker features were effective only when flankers produced relatively weak crowding effects. This strongly supports the notion that crowding might be functional in protecting the organism from information overload (e.g. Eberhardt & Huckauf, 2019; Herzog, Hermens, & Öğmen, 2014). In addition, the fact that higher-level effects on crowding go along with rather small crowding effects suggests that processing higher-level information of flankers might help to reduce crowding effects. That is, re-entering higher-level flanker information serves to disentangle low-level interactions among target and flankers.

However, at this point, it is important to address that for targets, distance to the observer did produce different effects (see also Eberhardt & Huckauf, 2020): close targets suffered more from crowding than far targets (Experiment 2). This finding seems to contradict the suggestion of a processing benefit in the observer-relevant close space drawn from the effects observed in Experiment 1 with flankers varying in depth. At this point, we can only speculate whether the impact of stimulus depth and stimulus emotion trace back to two separate processes taking place one after the other. Although we are still far from a full understanding of the underlying mechanisms, the real depth presentation seems to provide useful insights: hence, independently varying the distance in depth of flankers and of the target provides a method to disentangle effects of target and of flanker processing contributing to crowding effects.

Emotion of defocused stimuli affected crowding in the present study only when flankers were conditioned. We made various attempts to also uncover a clear effect of target emotion by investigating the effect of conditioned target emotion on crowding in several experiments using different depth manipulations (Pittino et al., 2019 versus Experiment 1b versus Experiment 2) and different dependent measures (Experiment 1b versus Experiment 2 and Pittino et al., 2019). Nevertheless, in none of the experiments was this successful. In both experiments of the present study (Experiment 1b and Experiment 2), only descriptively an effect of target emotion was observed, replicating the finding of only a weak emotion effect for targets, which was already reported for two-dimensional presentation (Pittino et al., 2019). Thus, emotion in crowded targets is either not processed up to a level at which it receives a behavior-relevant meaning, or, if the crowded target's emotion was processed, its potential to affect behavior was suppressed by the presence of flanking stimuli. As

has been reported, also steady-state visually evoked potentials in electroencephalography (EEG) recordings suggest that crowding suppresses targets, but not flankers (Chicherov & Herzog, 2015). However, effects of emotional meaning have also been reported for crowded target stimuli. For example, Kouider, Berthet, and Faivre (2011) demonstrated clear affective priming effects of crowded emotional faces surrounded by flanker stimuli. But note that in Kouider, Berthet, and Faivre (2011), crowded target emotion elicited priming effects for a subsequent stimulus, whereas recognition of the crowded target itself was not assessed.

In conclusion, we replicated that distance to fixation in depth shapes crowding effects, and that conditioned emotion of targets only scarcely affects crowding. Conditioned emotion of flankers, however, affects crowding, but only when flankers are presented closer than or at the fixated distance. Flankers behind the fixated distance did produce a larger crowding effect which, however, did not depend on the conditioned emotion of the flankers. These findings suggest that crowding protects the system from too much irrelevant information. They further insinuate that the observer's fixation depth might act as a reference for both, effects of emotion and crowding, probably framing the space into observer-relevant close areas, and observer-irrelevant distant areas.

Keywords: crowding, depth perception, emotion, evaluative conditioning

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