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# Enhanced early visual processing after evaluative conditioning

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ABSTRACT

The emotional significance of a stimulus is known to influence attentional selection leading to prioritization even at early stages of visual perception (e.g., selection from iconic memory). However, as the emotional meaning can be confounded with physical stimulus properties, it is possible that the prioritization is not driven by emotional factors alone. Here we use evaluative conditioning to manipulate the emotional meaning of arbitrary visual stimuli by repeatedly pairing each stimulus with either positive, negative, or neutral pictures. The subjective liking of conditioned stimuli (CSs) revealed reliable evaluative conditioning effects. Sensory processing advantages were measured by presenting the CSs in an iconic memory task asking participants to identify a target in a display of briefly presented stimuli. An adaptive variation of exposure durations revealed that shorter durations were required for the recognition of targets that were previously paired with negative or positive images than for neutral targets, indicating prioritized selection of affective CSs from iconic memory. Two additional experiments investigated the subsequent decay of information that was initially available in iconic memory by manipulated the delay of the recognition cue. Results show that positive CSs were more likely to be selected from iconic memory than neutral CSs, whereas negative CSs were prioritized in terms of prolonged availability in iconic memory. Taken together, the findings suggest that the affective learning history leads to prioritization at the level of iconic memory.

Fast and accurate sensory processing of important visual targets is required in many situations of daily life. For instance, the sudden appearance of a deer or a pedestrian on the road ahead of a driver may call for an immediate response in order to avoid an accident. Early object identification and fast allocation of visual attention are needed in such situations in order to quickly select an appropriate response. The visual system thus needs to rapidly and efficiently scan the visual field in order to isolate relevant targets from irrelevant distractors and to allocate selective attention to the subset of relevant information. In line with a distinction between top-down and bottom-up processes, it has been shown that the attentional selection and prioritization of a stimulus is driven by physical properties of the stimuli as well as the observer's current goals and expectations (e.g., Beck & Kastner, 2009; Jonides, 1981). On the one hand, attention can be captured involuntarily by certain stimuli depending on their distinctiveness relative to the context (e.g., a red square surrounded by blue circles is prioritized over a blue square surrounded by blue circles), and it has been shown that physical saliency maps based on perceptual contrast algorithms predict the location of both visual and auditory selective attention (Itti & Koch, 2000; Kayser, Petkov, Lippert, & Logothetis, 2005). On the other hand, it is well known that attention can also be voluntarily directed towards a stimulus depending on the current task goals (e.g., Wolfe, Cave, & Franzel, 1989; Yantis, 2000). However, in addition to this dichotomy between bottom-up and top-down influences, selective attention and the priority of stimulus processing also seems to be depend on the selection and reward history associated with a stimulus (e.g., Anderson, 2013; Awh, Belopolsky, & Theeuwes, 2012) as well as on the emotional or social significance (e.g., Mather & Sutherland, 2011), which may be unrelated to both physical saliency of the stimulus and the current goals of the individual. For instance, it has been shown with various paradigms that previous experience with the reward value or task relevance of a stimulus or stimulus features (i.e., the learning and reward history) affects the prioritization of the stimulus in a subsequent phases regardless of saliency or relevance of the stimulus for that task (Anderson, Laurent, & Yantis, 2011a; Feldmann-Wüstefeld, Uengoer, & Schubö, 2015; Hickey, Chelazzi, & Theeuwes, 2010; Le Pelley, Vadillo, & Luque, 2013; Pearson et al., 2016).

In addition to these influences of physical saliency, current goals, and learning history on selective attention, the prioritization of selective stimulus processing also depends on the emotional significance of a perceived stimulus, with a large body of evidence suggesting that emotionally meaningful stimuli are more likely to be attended and

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receive prioritized sensory and cognitive processing (for a review see Vuilleumier, 2005). For instance, it was found that emotional, and in particular fear-relevant stimuli are detected faster than neutral stimuli in visual search tasks (e.g., Frischen, Eastwood, & Smilek, 2008; Öhman, Flykt, & Esteves, 2001; Öhman, Lundqvist, & Esteves, 2001), and even patients with unilateral visual neglect were shown to be less likely to miss schematic drawings of spiders presented on the side of the neglect, compared to drawings of flowers or rings (suggesting unique pathways for emotional attention; Vuilleumier & Schwartz, 2001). Using an attentional blink paradigm, Anderson and Phelps (2001) further demonstrated that healthy participants were less likely to miss the second of two targets in a rapid series of visual stimulus presentations when it was emotionally arousing, whereas there was no prioritization of aversive targets (i.e., an attentional blink effect) in patients with bilateral amygdala damage. In line with the arousal-biased competition account (Mather & Sutherland, 2011), these results suggest that emotional arousal enhances the priority of stimulus selection, enabling the detection of a stimulus that would normally be hidden by an attentional blink. In line with this account, it has been found that the presentation of a loud arousing sound prior to the presentation of multiple visual targets of high and low contrast increased the bias to recall high-contrast targets, suggesting that arousal may further enhance the selection of high-priority information while reducing the representation of low-priority stimuli (Sutherland & Mather, 2012). While the physically salient high-contrast stimuli are generally more likely to be selected for further processing, these results indicate that (negative) arousal further increases the amount of selective attention directed to these stimuli resulting in enhanced availability in short-term memory.

However, the emotional arousal was also shown to affect earlier sensory processes. For instance, the perceptual contrasts needed to identify the orientation of a grating was found to be lower when the position of the grating was cued by a fearful face, as compared to when it was cued by a neutral face (Phelps, Ling, & Carrasco, 2006), suggesting that the emotional significance is already processed at early stages of visual perception. In line with the assumption of early prioritization, emotional stimuli were shown to lead to an early posterior negativity of event-related brain potentials (200–350 ms after stimulus onset; Schupp et al., 2007), and emotional biases were found also for the recognition of briefly presented visual stimuli, with negative stimuli being more likely to be encoded than neutral or positive stimuli (Jackson, Wu, Linden, & Raymond, 2009). In this study, participants were required to remember the identity of up to four briefly presented faces by indicating whether a subsequently presented single probe face was present or absent in the stimulus array. Higher recognition accuracy was observed for faces with angry expressions (face expression was irrelevant), as compared to faces with neutral and positive expressions. Moreover, there is evidence indicating that emotional stimuli are already more likely to be selected from sensory memory. In a study by Kuhbandner, Spitzer, and Pekrun (2011), drawings of multiple objects were presented simultaneously for a brief period of time (129 ms), and participants were asked to report a particular object that was presented at a cued location. The authors found that recall accuracy was higher for emotionally meaningful objects (e.g., gun, spider or heart), as compared to neutral objects (e.g., tree, fish, or deer). In addition, the slower decay with increasing cue delay in the case of threatening stimuli indicated that the time during which fear-relevant information is available for selection from iconic memory may be longer than for positive and neutral information.

To study emotional effects on visual perception and memory, researchers have typically used unconditioned emotional stimuli which are considered as evolutionarily significant (i.e., potentially relevant for survival), such as images of snakes spiders, or facial expressions (Öhman, Flykt, & Esteves, 2001; Öhman, Lundqvist, & Esteves, 2001). One caveat with the above-mentioned studies is that the emotional meaning of the stimuli used may often be confounded with certain physical stimulus properties such as luminance, shape, texture, energy, and contrast. For instance, it has been found that the faster visual detection of happy faces can be explained in terms of the bottom-up orienting responses triggered by the saliency of individual stimulus features (e.g., due to differences in the mouth region; Calvo & Nummenmaa, 2008). Also in studies using stimuli other than faces (e.g., Kuhbandner et al., 2011), the emotional stimuli such as spiders seem to differ considerably in terms of the overall luminance, contrast, and complexity from the stimuli that are typically used as neutral or positive stimuli such as a tree or a heart symbol. As such, an image of a spider may be detected faster than neutral images such as a tree, a dog, or a fish due, not because of its link to emotions (e.g., fear), but instead due to high-saliency features such as the spider's legs (e.g., higher luminance or spatial frequency). It is thus important to demonstrate effects of emotional significance with stimuli that are physically identical using conditioning to manipulate the emotional valence of the stimuli.

Given that associative learning has become an integral component of several theories of emotion (Ledoux, 2000) and attention (Anderson, 2016; Awh et al., 2012; Le Pelley, Mitchell, Beesley, George, & Wills, 2016), there is reason to suspect that sensory processing advantages will be observed also for stimuli whose emotional value has been learned through experience. The emotional meaning or the liking of an arbitrary stimulus (the conditioned stimulus; CS) can be changed easily using an evaluative conditioning procedure in which the stimulus is paired repeatedly with an unconditioned stimulus such as a pleasant or unpleasant picture (see Gast, Gawronski, & De Houwer, 2012). The use of an evaluative conditioning procedure allows the affective effects of emotional stimuli to be disentangled from processing advantages that are due to perceptual saliency of the stimulus. Specifically, stimuli with identical or randomly assigned physical stimulus properties and feature saliency can be used as neutral and emotional stimuli.

Surprisingly, however, only a few studies have yet investigated the effect of evaluative conditioning on measures of early sensory processing. In an attentional blink study by Lim and colleagues, emotionally arousing stimuli were found to be prioritized even when the arousing stimuli did not differ physically from the neutral stimuli (Lim, Padmala, & Pessoa, 2009). Specifically, the authors used a conditioning procedure to associate some of the target (faces and visual scenes) with high-arousal stimuli and others with low-arousal (neutral) stimuli, and they found that the high arousal-conditioned stimuli were later less likely to be missed as the second target in the attentional blink paradigm than the neutral stimuli. Similarly, in another study using a modified version of the attentional blink paradigm, aversively conditioned task irrelevant images were found to produce more interference with the response to a subsequently presented target (i.e., a rotated image) in a rapid series of images than neutral distractors did (Smith, Most, Newsome, & Zald, 2006). Pairing a CS with an aversive noise stimulus was also shown to have a small but replicable effect on attentional capture in a spatial cueing task, with longer reaction times being observed on trials containing an incongruent spatial cue if that cue had been paired previously with an aversive noise, as compared to a neutral cue (Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004, 2005). However, the response to the target stimulus was impaired only when the lag between the distractor and the target was short (200 ms), whereas no effects of aversive conditioning were found with a longer lag (800 ms), suggesting recovery from emotional distraction within that period of time.

Although the abovementioned studies primarily found attentional biases after aversive conditioning, there is also evidence indicating that attentional capture is sensitive to learned positive evaluations (Anderson, Laurent, & Yantis, 2011b; Pearson et al., 2016; Wang, Yu, & Zhou, 2013). For instance, visual search times for a target (a unique shape) were shown to be slower when there was a stimulus among the distractors that had been associated previously with higher monetary rewards (Anderson et al., 2011a).

While the above studies demonstrated that visual selective attention is sensitive also to the learned emotional meaning of a stimulus, the effect of affective conditioning on measures of early visual processing at the stage of iconic memory has not yet been studied. The aim of the present study is to close this gap by investigating whether the conditioned emotional valence of a stimulus leads to the same prioritization in terms of the selection of briefly presented stimuli as it was shown for unconditioned emotional stimuli such as angry faces and spiders (Jackson et al., 2009; Kuhbandner et al., 2011).

Interestingly, research on evaluative conditioning has focused almost entirely on the attentional and cognitive prerequisites and moderators of the changes in the liking of a stimulus (e.g., contingency awareness and attention; Corneille, Yzerbyt, Pleyers, & Mussweiler, 2009; Field & Moore, 2005; Fulcher & Hammerl, 2001; Kattner, 2012), whereas the consequences of evaluative conditioning for sensory processing have rarely been studied (for a study on the effects of evaluative conditioning on time perception, see Kliegl, Watrin, & Huckauf, 2015). It has been shown, however, that associative contingency learning induces sensory and attentional biases at early stages of visual processing (e.g., longer gaze dwell times, spatial cueing effects at short delays, and lower threshold durations for simple stimulus recognition; Le Pelley, Beesley, & Griffiths, 2011; Le Pelley et al., 2013; O'Brien & Raymond, 2012), suggesting that learning does not only depend on the availability of sensory and cognitive resources, but also induces changes in the associability of a stimulus, as reflected by the amount of selective attention that is directed to the stimulus (Mackintosh, 1975). If evaluative conditioning was based on the same mechanism as other forms of associative learning (as suggested by propositional accounts; De Houwer, 2009), then it may be expected that affective stimulus pairings will not only change the subjective valence of the CS, but also yield sensory and cognitive processing advantages (e.g., prioritized selection of CSs from iconic memory).

In the present study, we test whether changes in the valence of a stimulus resulting from evaluative conditioning affects the selection of that stimulus already at the level of iconic memory. Therefore, multiple stimuli were presented for a brief period of time and participants were asked to recall a target stimulus as a function of (a) the exposure duration of the stimuli (Experiment 1) and (b) the delay of the cue indicating which stimulus to recall (Experiments 2a and 2b). Prior to this task, stimuli were paired either with neutral or affective pictures to change the valence of the stimuli via evaluative conditioning. We predict that positive and negative CSs are more likely to be selected from iconic memory for further processing than neutral stimuli. Moreover, by manipulating the delay between stimulus presentation and recognition cue in Experiments 2a and 2b, we also test whether evaluative conditioning affects the decay of information that was initially available in iconic memory.

## 1. Experiment 1

### 1.1. Methods

#### 1.1.1. Participants

A total of thirty healthy participants (16 women, 15 men) with normal or corrected-to-normal vision were recruited at the University of Wisconsin-Madison to participate in Experiment 1 (corresponding to the sample size needed to obtain a medium-size within-subjects evaluative conditioning effect of $d = 0.52$, as reported in Hofmann, De Houwer, Perugini, Baeyens, and Crombez (2010), with a statistical power of $1\text{-}\beta = 0.87$). Ages ranged between 18 and 22 years ($M = 18.6$; $SD = 1.0$). All participants were compensated with course credit.

#### 1.1.2. Apparatus and stimuli

The experimental routines were programmed in MATLAB (Mathworks, Natick, MA, USA) utilizing the Psychophysics toolbox extensions (Brainard, 1997; Pelli, 1997). The participants were seated about 60 cm from a 20-in. Dell LCD monitor with a resolution of 1680 × 1050 pixels. Stimuli were presented by a NVIDIA GeFORCE 8800 GTX video card.

A pool of sixteen monochrome versions of drawings showing presumably neutral everyday objects (e.g., basket, purse, pullover, suitcase, telephone, toaster, and watering can) were selected from the Rossion and Pourtois (2004) database and served as CSs. The highly salient color information was removed from the original images in order to match the discriminatory low-level features of the stimuli for the iconic-memory task (see below).

A total of 36 images were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008) and served as the USs with positive (showing landscapes and sports scenes like hang gliding, hiking, skiing, gymnastics or rafting; nos. 5626, 5629, 8030, 8034, 8161, 8190, 8200, 8210, 8370, 8420, 8470, 8496), negative (showing drug scenes, assaults, sad children, burnt faces, dead animals, guns, or injuries; nos. 2703, 2717, 2800, 2811, 3101, 3500, 3530, 3550, 6415, 8230, 9181, 9423), and neutral valence (showing everyday objects like a stool, an umbrella, a lamp, a keyring, a book, or a mug; nos. 7004, 7006, 7009, 7010, 7025, 7035, 7041, 7059, 7090, 7150, 7175, 7233). Both mean valence ratings ($M_{neutral} = 2.24$; $SD_{neutral} = 0.15$; $M_{positive} = 7.41$; $SD_{positivel} = 0.44$; $M_{negative} = 2.24$; $SD_{negative} = 0.37$) and mean arousal ratings ($M_{neutral} = 2.46$; $SD_{neutral} = 0.42$; $M_{positive} = 6.27$; $SD_{positivel} = 0.47$; $M_{negative} = 6.03$; $SD_{negative} = 0.57$), as reported in the database, differed significantly between the three valence categories, $p < .001$.

#### 1.1.3. Procedure

The entire experiment consisted of three successive phases: the conditioning procedure, the recognition test, and the evaluative rating phase.

For the conditioning phase, six drawings were selected randomly for each participant from the stimulus pool and served as the CSs. Each CS was paired with five randomly selected US pictures of equal valence. Two CSs each were paired with positive, negative, and neutral images. These thirty CS-US pairs were presented four times in random order, resulting in a total of 120 conditioning trials. Each trial started with a variable, normally distributed ($M = 1.5$ s; $SD = 0.1$ s) fixation period (inter-trial interval) showing a small circle in the center of the screen. Then, the CS and the US were presented successively for 1 s and 3 s, respectively, with no inter-stimulus interval. No responses were required during the conditioning phase, and the participants were instructed to simply watch the series of pictures during this stage.

After the conditioning procedure, participants received oral instructions for the iconic memory task. In this task, each trial started with a central black fixation circle presented on a white screen. After 500 ms, an array of eight stimuli was presented on the white screen, arranged in a circle around the fixation point (at 5° eccentricity). The target stimulus array always contained two CSs of the same valence (positive, neutral, or negative) and six drawings that were not presented during the conditioning phase. A single object was presented as a probe immediately after the offset of the array of targets and until the participant's response. Participants were asked to indicate whether the probe object was present among the eight targets or not by pressing the right or left arrow key, respectively. The word "correct" or "wrong" was presented on the screen as a feedback immediately after each response for 500 ms. On half of the trials, the probe was presented in the circular arrangement, and in half of the trials the probe was not in the target array. On the probe-present trials, there was probability of $p = .9$ that probe was one of the two CS objects (and with $p = .1$ it was one of the six remaining objects). In order to determine the minimum exposure duration needed to reach 71% accuracy for each CS valence category, the presentation duration of the target array varied as a function of the accuracy of previous responses using three interleaved 1-up/2-down staircase rules: The initial stimulus presentation duration was 300 ms for all three CS categories. The presentation duration for a CS category was increased by 25 ms after each incorrect response, and it was decreased by 25 ms after two successive correct responses. The

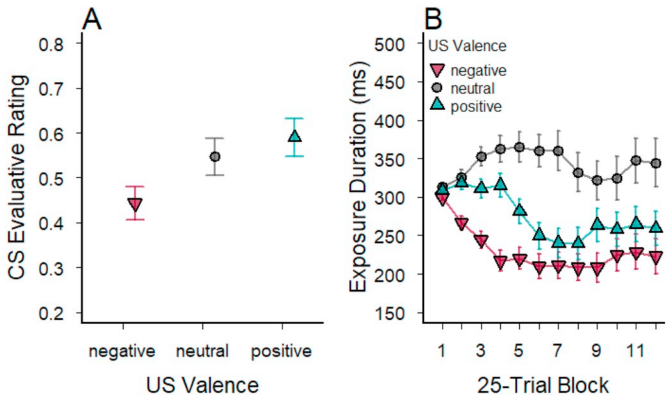


**Fig. 1.** Results of Experiment 1: (A) Subjective evaluative ratings of CSs varied as a function of the valence of the US they were paired with during the conditioning phase. (B) The exposure duration needed for recognize a stimulus (71% threshold) was lower for CSs that were paired with positive or negative USs, as compared to CSs that were paired with neutral USs. In both panels, error bars refer to ± one standard error of the mean.

recognition task consisted of a total of 300 trials (100 trials for each CS category), and different types of trials were presented interleaved and in random order.

At the end of the experiment, participants were asked to rate each CS by clicking with the mouse on a 21-point scale that ranged from "I totally dislike it" on the left (coded as 0) to "I totally like it" on the right (coded as 1). There were no tick marks or additional labels to the scale, and the six CSs were rated successively in random order.

### 1.2. Results

As illustrated in Fig. 1A, the mean evaluation of CSs that were paired with negative USs was lower than that for the CSs that were paired with neutral, and positive USs. The average evaluative ratings of CSs revealed a significant evaluative conditioning effect, as indicated by the main effect of US valence, $F(2,58) = 5.11$; $p = .01$; $\eta^2_G = 0.07$ (one-factorial repeated-measures ANOVA). Corrected pairwise *t*-tests controlling for the false discovery rate (Benjamini & Hochberg, 1995) confirmed a significant difference in evaluative ratings between negative and positive valence ($p = .02$) as well as between negative and neural valence ($p = .02$), but not between neutral and positive ($p = .15$) valence conditions. Interestingly, the individual subjective ratings of only 18 participants showed the expected differences in valence (i.e., positive CSs > neutral CSs > negative CSs), whereas the remaining 12 participants did not show this pattern of evaluative ratings.

The data from the iconic memory task of one participant who responded with the same key (right arrow) during the last 203 trials of the task were not included in the analysis. The data of four additional participants were removed due to technical problems with the stimulus presentation during the task. For the remaining 25 participants, Fig. 1B depicts the mean exposure durations of the stimulus arrays in the task as a function of the trial block following the three independent and interleaved staircase rules for CSs of different conditioned valence categories. As can be seen, lower exposure durations were needed for trials with CSs that were paired with negative or positive USs, as compared to trials with neutral CSs. A 3 (US valence) × 12 (trial block) repeated-measures ANOVA on the exposure duration revealed a significant main effect of US valence, $F(2,48) = 5.22$; $p = .01$; $\eta^2_G = 0.06$, with higher exposure durations for neutral CSs ($M = 342$ ms; $SD = 219$ ms) than for positive ($M = 276$ ms; $SD = 177$ ms) and negative CSs ($M = 230$ ms; $SD = 164$ ms). Pairwise *t*-tests corrected for multiple comparisons (Benjamini & Hochberg, 1995) revealed a significant contrast in exposure durations between negative and neutral CSs ($p = .01$), but not between positive and neutral CSs ($p = .11$), and not between positive and negative CSs ($p = .11$). There was also a significant interaction between US valence and block, $F(22,528) = 1.78$; $p = .02$; $\eta^2_G = 0.01$, suggesting that the difference between the three types of CSs was most evident later during the iconic memory task. Follow-up analyses revealed that the valence difference was not significant in the first block ($p = .32$), whereas it was significant ($p < .05$) from the second to the eighth block of the adaptive iconic memory task. The valence effect was not significant (or only marginally significant) in the subsequent blocks 9 ($p = .06$), 10 ($p = .14$), 11 ($p = .07$), and 12 ($p = .08$). There was no significant main effect of block on the exposure duration in the iconic memory task, $F(11,264) = 1.05$; $p = .41$.

Additional Bayesian analyses were conducted to contrast the likelihood of multiple models with fixed effects of block and valence as well as an interaction model to account for the exposure durations reached in the iconic memory task. Bayes factors calculated relative to a model with only random effects, revealed that a model 1 with only a fixed effect of valence (and block as a random effect) was most likely ($BF_{10} = 9.82 \cdot 10^{15}$), followed by a model 2 with two independent fixed effects for valence and block ($BF_{20} = 1.28 \cdot 10^{13}$) and an interaction model 3 ($BF_{30} = 1.30 \cdot 10^{10}$), whereas a model 4 with only block as a fixed effect was less likely than the full random effects model ($BF_{40} = 0.0009$).

### 1.3. Discussion

Experiment 1 provides some initial evidence for an effect of evaluative conditioning on the selection of CSs from iconic memory. Specifically, the exposure duration needed to select a target among a set of briefly presented visual stimuli (i.e., the 71% recognition threshold as estimated with the adaptive staircase procedure) was lower when the target had been paired previously with a negative US, as compared to when the target had been paired with a neutral US. This observation suggests that presenting a stimulus together with an affective US not only changes the subjective evaluation of that stimulus, but it also seems to lead to a prioritization of the selection from iconic memory for further processing enabling superior target recognition. We note, however, that the effect on positive CSs was attenuated as compared to negative CSs which might have resulted from the fact that the evaluative conditioning effect was also more pronounced for the negative than for the positive CSs (when comparing both to the ratings of neutral stimuli). Nevertheless, the results of Experiment 1 indicate that evaluative conditioning may be a useful paradigm to study emotional effects on early visual processing avoiding confounds between the emotional meaning and physical stimulus properties like complexity which could have been present in previous studies (e.g., differences in luminance, shape, or size; Kuhbandner et al., 2011).

It is not entirely clear from the results of Experiment 1 whether the observed effect of conditioned valence on the exposure duration needed to correctly recognize stimuli from iconic memory reflects (a) privileged attentional selection from iconic memory or (b) a prioritization in terms of enhanced or prolonged availability of the information in iconic memory. It is well known that information in iconic memory is available only for a very short period of time, and the benefit resulting from partial report (as compared to a whole report) disappears with increasing delay between the stimulus and the cue (see Gegenfurtner & Sperling, 1993). It has also been found that the decay of fear-related (threatening) information in iconic memory may be slower than the decay of neutral and positive information, whereas there seems to be no difference in terms of the initial availability of emotional and neutral information (Kuhbandner et al., 2011).

To extend the results of Experiment 1, the effect of evaluative conditioning on the properties of iconic memory was further investigated in additional experiments by manipulating the delay of the recognition cue. This allows to disentangle the effect of acquired emotional meaning on the selection of information in iconic memory from the effect on the initial availability and the subsequent decay of information in iconic memory. Previous results suggest, that emotional information may not only be prioritized in terms of the selection of information, but also in terms of prolonged availability of information in iconic memory (i.e., slower decay for negative targets; Kuhbandner et al., 2011). To test whether the decay of information in iconic memory is sensitive also to the emotional meaning that was acquired through evaluative conditioning, participants of Experiments 2a and 2b were required to perform a similar iconic task as in Experiment 1, but with varying delays between the stimulus presentation (with constant exposure duration) and the cue indicating which target was to be recalled.

## 2. Experiment 2a

Experiment 2a is a an extension of Experiment 1 with manipulations of the delay of the cue rather than the exposure duration during the iconic memory task in order to measure possible effects of the conditioned valence on the decay of CSs in iconic memory which is supposed to occur prior to attentional selection. The adaptive staircase procedure was replaced by a method of constant stimuli to measure recognition accuracy of CSs available in iconic memory as a function of the delay between stimulus presentation and cue (with the different delays being presented multiple times in random order).

### 2.1. Methods

#### 2.1.1. Participants

Forty-two participants (27 women, 15 men) with normal or corrected-to-normal vision were recruited for Experiment 2a at the University of Wisconsin-Madison ($n = 8$) and at the University of Hamburg ($n = 34$). Ages ranged between 18 and 45 years ($M = 22.7$; $SD = 5.1$). All participants were compensated with course credits in the respective University credit system. The data of three additional participants (two women, all tested at the University of Wisconsin-Madison) were not included in the analysis because recognition performance in the iconic memory task was not significantly above the chance level of 12.5% (9.4%, 13.1%, and 12.2%, $p > .05$).

#### 2.1.2. Apparatus and stimuli

The same hardware as in Experiment 1 was used to conduct Experiment 2a at the University of Wisconsin location. For the University of Hamburg location, an NVIDIA Quadro NVS 295 graphics card (on a Windows 7 computer with an Intel Core i5 processor) was used to present the stimuli on a 24″ DELL monitor. The same software was used at both locations for stimulus presentation and response registration (a script written in Matlab using the Psychophysics toolbox). Eight CSs were drawn randomly for each participant from the same set of sixteen monochrome drawings of objects (see Experiment 1), and thirty-six affective images as in Experiment 1 were used as CSs and USs in Experiment 2a, respectively.

#### 2.1.3. Procedure

Experiment 2a started with 120 conditioning trials in which the CSs were paired with affective images. Therefore, each CS was paired with three different USs of the same valence category and presented five times. Four CSs were paired with neutral US, two were paired with positive USs, and two were paired with negative USs (i.e., there was an equal number of neutral and affective pairings). The 24 CS-US pairings were presented in random order within each repetition block. As in Experiment 1, each trial started with a normally distributed fixation period showing a cross for $M = 1.5$ s ($SD = 0.1$) in the center of the screen. Then, the CS was presented for 1 s, followed by the CS superimposed on the US for 3 s. Unlike Experiment 1, a transparent version of the CS was on the US image using alpha blending ($\alpha = 0.5$) in order to enhance the likelihood of association formation. Participants were instructed to simply watch the series of pictures, and no responses were required during this stage.

The conditioning phase was followed by an iconic memory task with a total of 320 trials presented in random order. The procedure was adapted from Kuhbandner et al. (2011). Each trial started with a central fixation point (0.5° radius) for 500 ms. The eight CSs (size: 2°) were then shown in random order on a circle at 5° eccentricities around the fixation point for 136 ms (8 frames, corresponding approximately to the exposure duration used by Kuhbandner et al., 2011). After a variable delay (17, 68, 221, 493, 1003 ms) showing a blank screen, an arrow was presented pointing in the direction of one CS. The arrow pointed to each CS on 40 trials, resulting in 160 trials with a neutral CS as the target and 80 trials each with a target that was paired with a positive or negative US, respectively. All eight CSs were shown in the same size (2°) on the bottom fifth of the screen (in the same order from left to right on every trial, and separated by a horizontal line), and participants were asked to indicate which stimulus was presented at the location of the arrow by clicking on the respective image. After clicking an image, a short text feedback was presented for 500 ms indicated whether the choice was correct (in green font) or wrong (in red font) before the next trial started.

At the end of the experiment, participants were asked to rate the liking of the eight CSs in random order using the same evaluative rating scale as in Experiment 1.

### 2.2. Results

Fig. 2A shows that the evaluative ratings of CSs differed as a function of the valence of the USs with which the CSs were paired during the conditioning phase. This evaluative conditioning effect was confirmed by a significant main effect of US valence, $F(2,82) = 3.16$; $p < .05$; $\eta_G^2 = 0.03$. Pairwise $t$-tests corrected for multiple comparisons (Benjamini & Hochberg, 1995) revealed a significant valence difference between positive and negative CSs ($p < .05$), and between positive and neutral CSs ($p < .05$), but not between neutral and negative CSs ($p = .19$), suggesting that evaluative conditioning successfully increased the liking of CSs that were paired with positive images, but it did not decrease the liking of CSs that were paired with negative images. Similar to proportions in Experiment 1, the individual ratings of only 23 of the 42 participants showed differences in the expected direction for all comparisons between the three categories (positive CSs > neutral CSs > negative CSs).

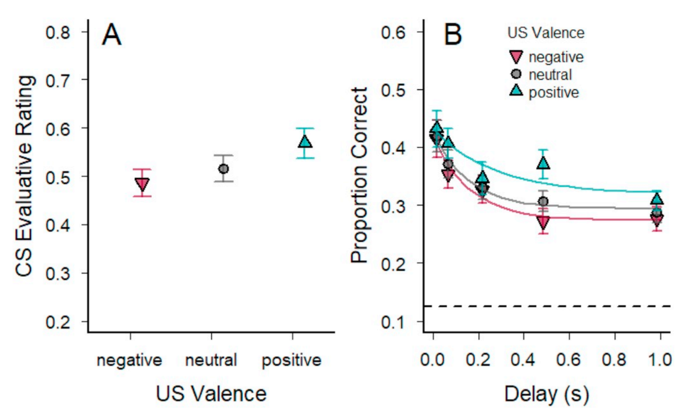


**Fig. 2.** Results of Experiment 2a: (A) Subjective evaluative ratings of CSs as a function of the valence of the US they were paired with during the conditioning phase. (B) Recognition accuracy for CSs presented in an iconic memory task as a function of the valence of the CS and the delay between target and recall cue. The solid lines represent exponential decay functions (see text), and the dashed horizontal line represents the chance level. Error bars in both panels represent ± one standard errors of the mean.

For the analysis of performance in the iconic memory task, the data of four participants with clearly reversed evaluative conditioning effects (i.e., mean ratings of CSs paired with negative USs $> 0.1$ above the mean ratings of CSs paired with positive USs) were not included. For the remaining participants, the average recognition accuracy as a function of the cue delay in the iconic memory task is visualized in Fig. 2B for the three types of CSs. It can be seen that recognition accuracy was higher for positive CSs than for neutral and negative CSs. A 5 (delay) × 3 (US valence) repeated-measures ANOVA on recognition accuracy revealed a main effect of delay, $F(4,148) = 19.88$; $p < .001$; $\eta_G^2 = 0.09$, indicating the typical decay of information in iconic memory with increasing cue delays. Corrected pairwise *t*-tests revealed that recognition accuracy differed significantly between all delay conditions ($p < .05$), except for the contrasts 221 vs 493 ms ($p = .18$) and 493 vs. 1003 ms ($p = .11$). More importantly, the ANOVA also revealed a significant main effect of US valence, $F(2,74) = 4.37$; $p = .02$; $\eta_G^2 = 0.02$, suggesting that recognition accuracy was slightly higher for positive CSs ($M = 0.37$; $SD = 0.16$) than for CSs that were paired with neutral ($M = 0.34$; $SD = 0.14$) or negative USs ($M = 0.33$; $SD = 0.16$). Consistent with the pattern of evaluative ratings, adjusted pairwise comparisons revealed significant differences in recognition accuracy between positive and negative CSs ($p = .01$) and between positive and neutral CSs ($p < .05$), but no difference between negative and neutral CSs ($p = .18$). There was no interaction between delay and US valence, $F(8,296) = 1.00$; $p = .44$; $\eta_G^2 < 0.01$, suggesting that the speed of decay with increasing cue delay did not differ as a function of the conditioned valence.

In addition to these frequentist statistics, Bayes factors were calculated for the likelihood of model 1 with a fixed effect of delay (and a random effect of US valence), model 2 with a fixed effect of US valence (and random effect of delay), model 3 with fixed effects of both delay and US valence, and model 4 with a delay × US valence interaction, relative to a random effects model. The most likely model given the data was model 3 assuming two independent fixed effects ($BF_{30} = 8.14 \cdot 10^{14}$), followed by model 1 with only a fixed effect of delay ($BF_{10} = 5.60 \cdot 10^{13}$) and the interaction model 4 ($BF_{40} = 8.95 \cdot 10^{12}$), whereas the lowest Bayes factor was obtained for model 2 ($BF_{20} = 5.96$). Hence, the data suggest that it is about 14.55 times more likely that recognition accuracy in the iconic memory task was influenced by both US valence and cue delay (model 3) than that it is affected only by the cue delay (model 1).

Exponential decay functions, $p(t) = \alpha e^{\frac{-t}{\tau}} + \beta$, were fitted to the proportion of correct recognitions as a function of the cue delay *t*, with $\alpha$ indicating the initial availability of information in iconic memory, $\beta$ corresponding to the amount of information that is selected for further processing (i.e., in visual short-term memory), and $\tau$ referring to the duration of information in iconic memory (with high $\tau$ referring to slow decay; see Graziano & Sigman, 2008; Lu, Neuse, Madigan, & Dosher, 2005). The decay functions with the best fit to the data, as obtained with an adaptive non-linear least-squares algorithm (Dennis, Gay, & Walsh, 1981), are shown in Fig. 2B. For the aggregated recognition accuracy, the initial availability parameter of the decay function was only slightly higher for positive CSs ($\alpha = 0.15$) than for neutral and negative CSs ($\alpha = 0.13$ and $\alpha = 0.11$, respectively). However, this difference in initial availability was not confirmed statistically for the decay functions fitted to the individual data, $\chi(2) = 3.05$; $p = .22$. In addition, the aggregated decay functions of positive CSs were characterized by higher values on the selection parameter ($\beta = 0.32$), as compared to the decay functions of neutral ($\beta = 0.29$) and negative CSs ($\beta = 0.27$), suggesting that positive CSs are more likely to be selected from iconic memory for further processing. This difference failed to reach significance for the $\beta$ parameter of individual decay functions though, $\chi(2) = 3.32$; $p = .19$. Moreover, differences in the temporal decay parameter $\tau$ indicate that the availability of positive CSs in iconic memory was somewhat prolonged ($\tau = 0.27$), as compared to neutral ($\tau = 0.16$) and negative CSs ($\tau = 0.16$), but again this difference was not significant for the decay functions fitted to individual data, $\chi(2) = 0.27$; $p = .87$. Hence, the conditioned valence does seem to affect the average recognition accuracy, but not the shape of the decay functions.

### 2.3. Discussion

Experiment 2a successfully replicated the finding that evaluative conditioning prioritizes the selection of information from iconic memory for CSs that acquired positive valence. In particular, recognition accuracy was higher for briefly presented targets that were paired with positive images in a previous conditioning phase, as compared to control targets that were paired with neutral images. The data further show that positive CSs were more likely to be selected, regardless of the delay of the cue. This indicates that evaluative conditioning affected the attentional selection of information in iconic memory for further processing, but not necessarily the speed of decay of information that was initially available in iconic memory. Fitted exponential decay functions, however, suggest that the initial availability of negative CSs may have been enhanced, compared to positive and neutral CSs (but this finding could not be confirmed statistically at the level of individual decay functions). In contrast to Experiment 1, no processing advantage was observed for CSs that were paired with negative images, which is most likely due to the less pronounced (and non-significant) evaluative conditioning effect for CSs that were associated with negative images. Hence, while the results suggest that the increased liking of a stimulus resulting from evaluative conditioning is reflected also in enhanced priority with regard to the selection of the stimulus from iconic memory, no such evidence was observed for disliked CSs. As it is unclear why evaluative conditioning did not induce a disliking of CSs in Experiment 2a, we therefore decided to run another replication of the experiment.

## 3. Experiment 2b

### 3.1. Methods

#### 3.1.1. Participants

Forty participants (25 women, 15 men) with normal or corrected-to-normal vision were recruited for Experiment 2b at the University of Wisconsin-Madison. Ages ranged between 18 and 24 years ($M = 19.9$; $SD = 1.5$). Participants were compensated with course. The data of one additional female participant were not included in the analysis because recognition performance in the iconic memory task was not significantly above chance level (15.3%, $p = .16$).

#### 3.1.2. Apparatus, stimuli, and procedure

The experimental was identical to Experiment 2a in terms of the apparatus (at the University of Wisconsin location), stimuli, and procedure.

### 3.2. Results

The evaluative ratings of CSs that were paired with positive, negative, or neutral USs during the conditioning phase of Experiment 2b are illustrated in Fig. 3A. There was a significant main effect of US valence, $F(2,78) = 12.93$; $p < .001$; $\eta_G^2 = 0.20$, suggesting that evaluative conditioning successfully changed the liking of CSs. Adjusted pairwise *t*-tests, however, revealed a significant rating difference between negative and neutral CSs ($p < .001$) as well as between negative and positive CSs ($p < .001$), but not between neutral and positive CSs ($p = .32$). Hence, in contrast to Experiment 2a, evaluative conditioning significantly reduced the liking of CSs that were paired with negative USs, but it did not enhance the liking of positive CSs. Looking at individual EC effects, 27 out of 40 participants showed the expected shifts

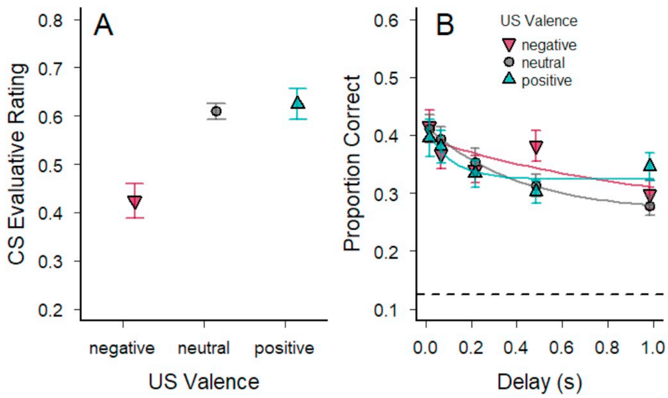


**Fig. 3.** Results of Experiment 2b: (A) Subjective evaluative ratings of CSs as a function of the valence of the US they were paired with during the conditioning phase. (B) Recognition accuracy for CSs presented in an iconic memory task as a function of the valence of the CS and the delay between target and recall cue. The solid lines represent exponential decay functions (see text), and the dashed horizontal line represents the chance level. Error bars in both panels represent ± one standard errors of the mean.

in evaluative ratings (i.e., a proportion similar to Experiments 1 and 2a).

Using the same criteria as in Experiment 2a, the data of seven participants with clearly reversed evaluative conditioning effects were not included for the analysis of iconic memory performance. The recognition accuracy of the three types of CSs in the iconic memory task of Experiment 2b is illustrated in Fig. 3B. A 5 (delay) × 3 (US valence) repeated-measures ANOVA revealed a significant main effect of delay, $F(1,128) = 13.02$; $p < .001$; $\eta_G^2 = 0.06$, suggesting a general decay of the information available in iconic memory. More importantly, the ANOVA also revealed a significant interaction between delay and US valence, $F(8,256) = 2.23$; $p = .03$; $\eta_G^2 = 0.02$, indicating that the shape of the decay functions differs as a function of the conditioned valence of the to-be-recalled targets. Unlike Experiment 2a, there was no main effect of US valence on recognition accuracy in Experiment 2b, $F(2,64) = 0.18$; $p = .84$; $\eta_G^2 < 0.01$. Pairwise comparisons adjusted for multiple comparisons (two-sided paired *t*-tests) revealed that negative CSs were more likely to be recognized at 483 ms cue delay than both neutral ($p = .04$) and positive CSs ($p = .03$), whereas there were no other valence differences.

Bayes factors were also calculated for the various fixed-effects models of recognition accuracy in Experiment 2b. While the models with two fixed effects of US valence and delay ($BF_{30} = 8514$) as well as the interaction model ($BF_{40} = 2159$) were much more likely than a random effects model, the most likely model in Experiment 2b was a model with a fixed effect of delay and a random effect of US valence ($BF_{10} = 268755$). The model with only US valence as a fixed effect was less likely than the random effects model ($BF_{20} = 0.03$).

Exponential decay functions were again fitted both to the average proportion of correct recognitions (see Fig. 3B) and to the recognition accuracy of each participant (for the statistical tests). For the aggregated data, there were no clear valence differences in terms of the initial availability in iconic memory ($\alpha_{positive} = 0.09$; $\alpha_{negative} = 0.13$; $\alpha_{neutral} = 0.15$) and the selection of information for further processing ($\beta_{positive} = 0.32$; $\beta_{negative} = 0.26$; $\beta_{neutral} = 0.27$). However, the temporal decay parameter was much higher for negative than for positive and neutral CSs ($\alpha_{negative} = 1.00$; $\alpha_{positive} = 0.40$; $\alpha_{neutral} = 0.11$), indicating prolonged availability (i.e., slower decay) of negative CSs in iconic memory. However, for the individual fits of exponential decay functions, there were again no significant differences in terms of the initial availability parameter α, $\chi(2) = 3.05$; $p = .22$, the attentional selection parameter decay β, $\chi(2) = 1.11$; $p = .57$, and the temporal decay parameter τ, $\chi(2) = 2.34$; $p = .31$.

### 3.3. Discussion

Experiment 2b revealed successful evaluative conditioning by increasing the disliking of CSs that were paired with negative USs, whereas no reliable positive evaluative conditioning effect was observed. The reason for this discrepancy between Experiments 2a and 2b is unclear, and it can only be speculated whether it has to do with sample differences (i.e., predominantly German sample in Experiment 2a and US sample in Experiment 2b) or the season of data collection (i.e., end of fall/winter term in Experiment 2a and beginning of spring term in Experiment 2b). Nevertheless, the results extend the findings of Experiment 2a in terms of the effects on iconic memory, demonstrating that the acquisition of negative valence through evaluative conditioning may also affect early sensory processing. However, while acquisition of positive valence was found to prioritize the selection of information from iconic memory (regardless of the cue delay) in Experiment 2a, the results of Experiment 2b suggest that learned negative valence affects primarily the decay of information that was initially available in iconic memory, but not the attentional selection of information. This functional discrepancy between positive and negative emotions in iconic memory is in consistent with previous results showing prolonged availability only for threatening stimuli, but not of positive information (Kuhbandner et al., 2011).

## 4. General discussion

The present study demonstrated that evaluative conditioning influences the selection of CSs from iconic memory. In two experiments, we observed that CSs that were paired with emotional images were more likely to be selected from briefly presented visual displays than CSs that were paired with neutral USs, suggesting privileged processing of acquired evaluative information. More specifically, Experiment 1 revealed that the exposure duration required to identify both negative and positive CSs at high accuracy was shorter than for the identification of neutral CSs, suggesting that the selection of emotional CSs from iconic memory is prioritized. In addition, Experiment 2a found that the recognition accuracy for positive CSs in displays with very short stimulus presentations was enhanced compared to neutral and negative CSs. This prioritization of positive CSs at low levels of accuracy was found to be independent of the delay of the cue, suggesting that evaluative conditioning affected the attentional selection, but not the decay of information in iconic memory. The parameters of exponential decay functions further suggest that the initial availability of negative CSs may have been slightly enhanced compared to positive and neutral CSs, though this prioritization was not present in terms of the subsequent attentional selection of the CSs. Together, the results for positive CSs are consistent with previous findings of prioritized attentional selection of emotional information in iconic memory (Kuhbandner et al., 2011)

The results of Experiment 2b further show that the decay of negative CSs in iconic memory seems to be slower than the decay of neutral and positive CSs, suggesting prolonged availability of negative information in iconic memory. In contrast to the effects observed for positive CSs in Experiment 2a, Experiment 2b did not reveal evidence of prioritized attentional selection for negative CSs. To that effect, the results are consistent with a previous iconic memory study using emotional targets (reporting slower decay for threatening but not for positive targets; Kuhbandner et al., 2011), indicating prolonged availability of negative targets which acquired their valence through evaluative conditioning.

Numerous previous studies found that selective attention is directed with priority to emotional stimuli even when the emotional meaning is irrelevant for the current task (e.g., Anderson & Phelps, 2001; Hodsoll, Viding, & Lavie, 2011; Öhman, Flykt, & Esteves, 2001; Smith et al., 2006). Moreover, it has been shown that the emotional meaning of a stimulus is related to lower visual thresholds (i.e., contrast sensitivity of orientation discriminations; Phelps et al., 2006), enhanced selection of information from iconic memory (Kuhbandner et al., 2011), and more accurate recognition of items in visual short-term memory (Jackson et al., 2009). However, since emotional stimuli may often differ from neutral stimuli in terms of their physical saliency (as outlined above), proper stimulus matching is crucial for drawing firm conclusions about the causal effect of emotional associations. Such a causal link between emotion stimulus meaning and attention has been observed previously within the attentional blink paradigms, showing that stimuli which were conditioned to be aversive were less likely to be missed as the second targets in a rapid series of visual presentations (Lim et al., 2009). The present study extends these findings to an iconic memory paradigm, showing that emotional valence as acquired through evaluative conditioning affects the selection of briefly presented stimuli that were registered only in iconic memory. In addition, there is also some indication of a valence asymmetry in terms of the effects on iconic memory, with a slower decay only for negative, but not for positive CSs that were available in iconic memory. To the best of our knowledge, our study is the first to provide evidence for evaluative conditioning to affect iconic memory, suggesting that previously observed processing advantages (Kuhbandner et al., 2011) may actually be due to the emotional meaning of the stimulus rather than confounded physical stimulus properties. The results also demonstrate that evaluative conditioning is a useful method to manipulate the emotional meaning of arbitrary and physically matched stimuli in order to study emotional effects on early sensory processing.

The results are consistent with the assumption of privileged perceptual and attentional processing of emotional stimuli in general (Vuilleumier, 2005) as well as with the arousal-biased competition account assuming that arousal enhances the priority of a selected stimulus for perception and memory (Mather & Sutherland, 2011). Specifically, the results indicate that the emotional arousal of CSs that were paired with positive or negative affective pictures enhances the priority of selective stimulus processing already with regard to the read-out of information from iconic memory.

The present findings also suggest that the repeated co-occurrence of a CS with an affective stimulus may not only change the valence of the CS, but also leads to a prioritization of sensory processing. This is consistent with the idea that evaluative conditioning (like other forms of associative learning) may be driven by a learning mechanism that changes the associability of the CS (Mackintosh, 1975). In line with evidence from the predictive learning literature (e.g., Le Pelley et al., 2013; O'Brien & Raymond, 2012), the present results indicate that these changes in the associability of affective CSs may be present already at very early stages of visual processing. This pattern of results fits very well with recent accounts of selective attention in which the selection and reward history is proposed as a third source of attentional biases, besides bottom-up (saliency-driven) and top-down (goal-driven) control processes (Awh et al., 2012). Several studies have shown prioritization for stimuli that have been previously attended (e.g., because they were task-relevant or associated with reward), even if (a) the previously attended stimuli are less salient than other distractors in the current task and (b) the acquired selection bias contradicts the correct selection goals (e.g., Anderson, 2013; Hickey et al., 2010; Theeuwes & Van der Burg, 2011). The present results are consistent with these findings, demonstrating that the passive experience of simple pairings in an evaluative conditioning procedure can also be a source of attentional selection biases. This suggests that it is not necessary for a stimulus to be task-relevant or associated with a monetary reward in order to be prioritized for attentional selection. Instead, the experience of emotional arousal together with the presentation of a stimulus seems to be sufficient to dominate in the contest of selective attention (compare Mather & Sutherland, 2011).

Taken together, the series of experiments presented here provide evidence for affective-evaluative learning to affect not only the subjective evaluation of CSs, but also to induce selection biases at the level of iconic memory. Enhanced attentional selection was observed for CSs that were presented together with affective pictures, as compared to neutral CSs. While Experiment 1 indicated that shorter presentation durations are required for the identification of negative and positive CSs, Experiment 2a further demonstrated that the prioritized attentional selection of CSs from iconic memory occurs also with longer delays of the cue, suggesting that evaluative conditioning did not affect the decay of information that was initially available in iconic memory. In addition, there is some indication also for a prioritization of negative CSs in terms of a slower decay of information in iconic memory.

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