AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Experimental Psychology:
Human Perception and Performance

ISSN: 0096-1523

2021, Vol. 47, No. 8, 1043–1055
https://doi.org/10.1037/xhp0000923

No Effect of Value Learning on Awareness and Attention for Faces: Evidence From Continuous Flash Suppression and the Attentional Blink

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It is widely believed that the emotional and movtivational value of social signals, such as faces, influences perception and attention. However, effects reported for stimuli with intrinsic affective value, such as emotional facial expressions, can often be explained by differences in low-level stimulus properties. To rule out such low-level effects, here we used a value-learning procedure, in which faces were associated with different probabilities of monetary gain and loss in a choice game. In three experiments involving 149 participants, we tested the influence of affective valence (win- vs. loss-associated faces) and motivational salience (probability of monetary gain or loss) on visual awareness, attention, and memory. Using continuous flash suppression and rapid serial visual presentation, we found no effects of affective valence or motivational salience on visual awareness of faces. Furthermore, in two experiments, there was no evidence for a modulation of the attentional blink, indicating that acquired emotional and motivational value does not influence attentional priority of faces. However, we found that motivational salience boosted recognition memory, and this effect was particularly pronounced for win-associated faces. These results indicate that acquired affective valence and motivational salience affect only later processing of faces related to memory but do not directly affect visual awareness and attention.

Public Significance Statement
This study shows that pairing faces with monetary reward affects memory but not visual awareness or temporal attention.

Keywords: visual awareness, value learning, reward, continuous flash suppression, attentional blink

The world contains myriad visual stimuli, but only a limited amount of this information enters conscious awareness. One factor that can influence which stimuli receive attention and enter awareness is emotional and motivational value (Bourgeois et al., 2016; Hedger et al., 2016). Much evidence for emotional prioritization has been acquired with continuous flash suppression (CFS), a strong interocular suppression technique (Tsuchiya & Koch, 2005). Following initial suppression, stimuli with intrinsic emotional value, such as emotional facial expressions or emotional body postures, break through CFS and become visible more quickly than nonemotional stimuli (Stein, 2019; Yang et al., 2007; Zhan et al., 2015). Such effects are often considered evidence for unconscious processing of emotional stimuli, perhaps involving specialized neural circuitry (Tamietto & De Gelder, 2010), resulting in privileged entry to perceptual awareness.

One issue for studies using stimuli with intrinsic emotional value is that these stimuli differ not only in emotional meaning but also in terms of lower-level image properties, such as shape, texture, phase, amplitude, and spatial frequency spectrum. Indeed, several effects are better explained by differences in such low-level properties than by differences in emotional-motivational value (Gayet et al., 2019; Gray et al., 2013; Moors et al., 2019). For example, shorter suppression times for fearful faces in CFS reflect higher effective contrast rather than enhanced processing of threat (Hedger et al., 2015). Similarly, the influence of facial dominance on breaking CFS is related to local contrast in the face's eye regions rather than to social evaluation (Stein et al., 2018). One elegant way of ruling out the influence of low-level stimulus properties is to use stimuli that differ only with regard to their affective learning history. For example, Gayet et al. (2016) found shorter suppression times for colored annuli that had been paired with electric shock in a fear conditioning procedure. However, whether such effects of affective learning extend beyond conditioning of basic visual stimuli (e.g., colors, gratings; Padmala & Pessoa, 2008) with threatening unconditioned stimuli (such as shocks) is currently unknown.

In our daily social lives, we routinely pair other people with affective information, such as value or affective semantic information

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such as emotional stories and episodes. However, two previous studies in which images of human faces were paired with affective information did not find an effect on breaking CFS (Rabovsky et al., 2016; Stein et al., 2017). These studies used affective-learning protocols where participants learned to associate affective stories with particular face exemplars (e.g., negative story "Fired an employee before Christmas"). Thus, in contrast to the classical fear conditioning procedure by Gayet et al. (2016), affective learning involved semantic processing (associating affective stories with face exemplars). Furthermore, while in the classical fear conditioning paradigm, stimuli were paired with a direct negative outcome for participants (a shock), faces were not. Here, we tested the influence of reinforcement learning on awareness of faces. Faces were associated with different probabilities of monetary gain and loss in a choice game, thus equipping the face stimuli with direct affective and motivational relevance for participants.

We adopted an established value-learning procedure, where faces were paired with different probabilities of monetary gain and loss. In previous studies using this choice game, expected value influenced visual processing of faces. For example, Raymond and O'Brien (2009) found distinct effects of motivational salience (probability of monetary gain or loss) and affective valence (gain or loss) on recognition memory in an attentional-blink (AB) paradigm. In the AB task, participants indicated whether a face had previously been presented in the choice game. Participants were asked to identify a first stimulus, and faces followed this stimulus with a short or long temporal lag. At short lags, face recognition suffered, reflecting reduced temporal attention characteristic of the AB. Faces with high motivational salience (high probability of an outcome in the choice game) were more often recognized correctly, independent of whether attention was fully available or reduced (long vs. short lags in the AB task). In contrast, affective valence influenced attentional priority, virtually eliminating the AB for faces that had been paired with monetary gain, indicating that "attention and motivation provide separable, independent top-down signals for controlling perceptual awareness" (Raymond & O'Brien, 2009).

However, as this study measured how well participants could remember faces from the value-learning task, these effects could reflect differences in memory unrelated to perceptual awareness. The effect of motivational salience, which was independent of lag, could reflect differences in long-term memory or differences in response criterion and memory confidence. For example, for faces with higher motivational salience, participants may have simply been more confident that they had seen the face before, rather than perceiving the face more clearly. The reduced AB for win-associated faces could similarly reflect memory prioritization rather than attentional enhancement of perceptual awareness.

Indeed, in line with the possibility that observed differences were due to differences in memory, other studies that tested the influence of value learning on face processing but did not require memory retrieval yielded mixed results. For example, in an attentional cuing study, targets were preceded by spatially congruent or incongruent face cues Rutherford et al. (2010). At short cue-target stimulus onset asynchronies (SOAs; 100 ms), where one would expect effects of rapid spatial orienting, overall responses tended to be slower when win-associated faces were used as a cue, and there was no evidence for attentional cuing by faces with high motivational salience or positive valence (Rutherford et al., 2010). Similarly, measuring perceptual discrimination of faces and scrambled faces with speeded saccades, Rothkirch et al. (2013) reported no evidence for faster detection of win- or loss-associated faces compared to neutral faces that had never been paired with a monetary outcome. Such absence of effects on attention and perception is consistent with a functional MRI study that found differential activity in reward-related areas in orbitofrontal cortex following value learning but no modulation of visual cortex or fusiform face area (Rothkirch et al., 2012). Together, these results are difficult to reconcile with the idea that acquired value influences attentional priority and visual awareness of faces.

To test whether learned affective valence and motivational salience influence awareness of faces, in Experiment 1 we measured suppression times using breaking CFS (Jiang et al., 2007; Stein, 2019) for faces that differed in expected value following a value-learning task. To anticipate our results, although participants successfully learned to choose the optimal faces in the value-learning task, neither motivational salience nor affective value influenced awareness of faces during CFS. To determine whether this reflected the perceptual nature of our task (simple localization) or the fact that CFS abolished stimulus processing early in the visual system, we conducted two attentional-blink (AB) experiments. These experiments allowed us to distinguish between effects on visual awareness, attention, and memory. In Experiment 2a (AB-localization), participants localized faces embedded in a modified rapid serial visual presentation (RSVP) sequence. With this simple localization task, there was no evidence for effects of motivational salience or affective value on awareness and attention. Experiment 2b (AB-recognition) was modeled after the study by Raymond and O'Brien (2009) but had substantially higher statistical power. Results revealed overall better recognition memory for faces with high motivational salience, in particular for win-associated faces, but no effects on attentional priority. Together, our results suggest that value associations for faces influence memory but not attention or awareness.

Experiment 1: Continuous Flash Suppression (CFS)

To determine whether acquired affective and motivational value can influence awareness of faces, we measured suppression times with a breaking CFS paradigm after faces had been paired with different probabilities of monetary gain and loss in a choice game. If motivational relevance boosted visual awareness, we would expect shorter suppression times for high- compared to low-probability faces, independent of affective valence (win or loss). If reward signals had attentional priority (Raymond & O'Brien, 2009), the effect could be expected to be larger for win-associated faces. Alternatively, if visual stimuli with negative valence were prioritized for awareness (Gayet et al., 2016; Yang et al., 2007), we would expect shorter suppression times for loss-associated faces.

Method

Participants

Fifty-eight undergraduate students were recruited through the Oberlin College participant pool. In both this and the subsequent experiments, we only tested participants who said they had normal or corrected-to-normal vision. In addition, all participants were naive to the research question and received either course credit or a small monetary compensation for their participation. Informed consent for Experiment 1 was obtained following a protocol approved by the Oberlin College Institutional Review Board. One participant was excluded because localization accuracy was only 56% correct; four other participants needed to be excluded because their data were not stored. The final sample consisted of 53 participants (41 female, mean age 19.3 years, *SD* = 1.4). Participants received written and verbal instructions and practice trials, and all experiments contained several short obligatory breaks.

Sample Size and Statistical Power

It was not clear which specific effect size reported in previous studies to base the power calculation on. In their AB-recognition study, Raymond and O'Brien (2009) report as the key effect a significant two-way interaction between lag and valence (indicating a reduced AB for win-associated faces) with an effect size d_z of .88. To achieve 80% power to detect this effect size, only 13 participants would have been required. We decided to test a much larger sample size to increase our chances of detecting a possible effect in the CFS experiment, resulting in > 99.9% power to detect an effect as large as reported by Raymond and O'Brien (2009) and in 80% power to detect effects $d_z > .40$. In Experiments 2a and 2b, we also had > 99.9% power to detect an effect as large as reported by Raymond and O'Brien (2009) and 80% power to detect effects $d_z > .42$, respectively.

Display and Apparatus

Stimuli were presented on a 24-in. LCD monitor (1,920-pixel × 1,080-pixel resolution, 60-Hz refresh rate) that participants viewed dichoptically through a custom-built mirror stereoscope using a chin-and-head rest placed approximately 84 cm away from the screen. The mirrors of the stereoscope were adjusted for each observer to yield stable binocular fusion. Experiments were programmed in MATLAB using Psychtoolbox (Brainard, 1997) functions. Presentation times were synchronized with the vertical refresh cycle of the screen. Two fusion contours (4.8° × 4.8° of visual angle) consisting of random black and white pixels (width .2°) were displayed side-by-side on the screen such that one contour was shown to each eye (distance between the centers of the two contours 10°). A small black fixation cross was presented in the center of each contour, and the remainder of the space enclosed by the contour was midgray. Participants were asked to maintain fixation throughout the CFS experiment (moving the eyes between trials if necessary).

Stimuli

Stimuli were photographs of 16 faces (eight female) with emotionally neutral expression from the FACES database (Ebner et al., 2010). Photographs were converted to grayscale and cropped to an oval (1.2° × 1.8°), removing hair and outer facial features. Pixel values within the oval were equated for mean and standard deviation. To induce CFS, we generated 170 masks (4.8° × 4.8°) consisting of randomly arranged circles of different sizes in black, white, and various shades of gray (diameter .1–.8°).

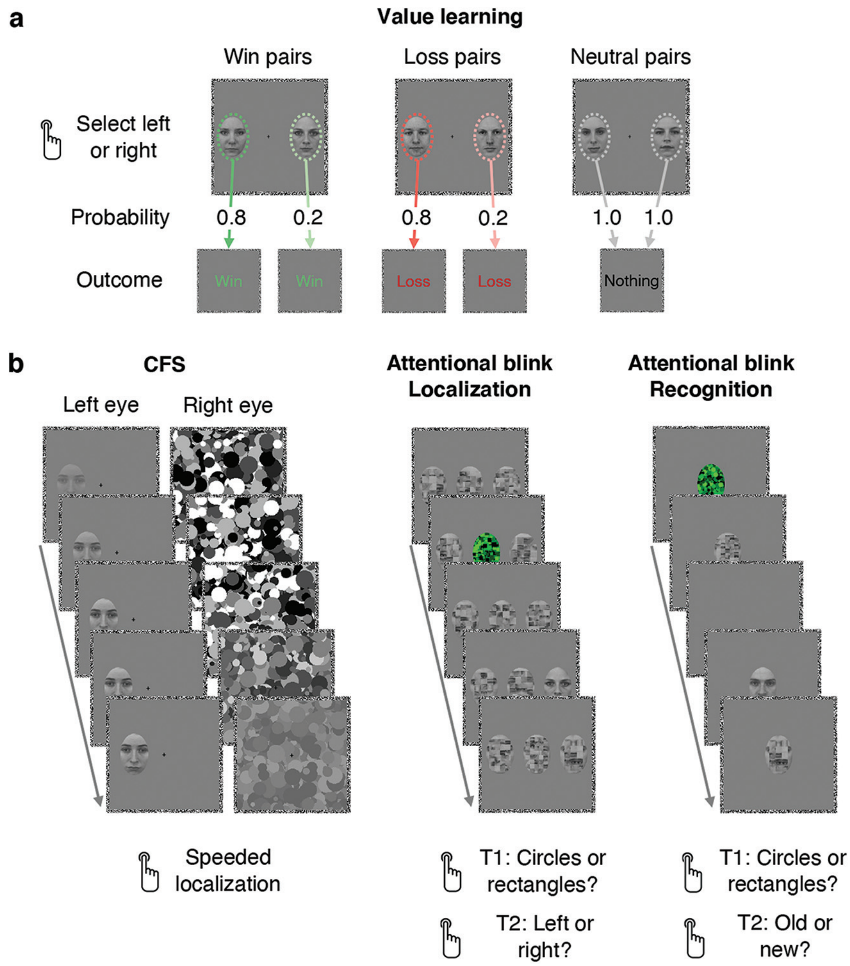
Value-Learning Task

Experimental sessions began with a choice game, in which participants could win a small amount of extra money (see Figure 1a). On every trial, participants selected one face from a pair of faces presented simultaneously to both eyes either left and right of fixation (half the trials, centered at an eccentricity of 1.4°) or above and below fixation (half the trials, centered at an eccentricity of 1.1°). There were two "win" pairs, two "loss" pairs, and two "neutral" pairs. For each type of pair, one of the two pairs consisted of two male faces and the other pair of two female faces. On win and loss trials, participants could win or lose 5 cents or gain nothing. For win pairs, the probability of winning 5 cents was 80% for one face exemplar (high motivational salience) and 20% for the other face exemplar (low motivational salience). For loss pairs, the probability of losing 5 cents was 80% for one face exemplar (high motivational salience) and 20% for the other face exemplar (low motivational salience). Neutral pairs never resulted in monetary gains or losses. The three types of pairs (win, loss, neutral) yielded five conditions differing in outcome probability (−.8, −.2, 0, .2, .8). Note that for consistency with previous studies (Raymond & O'Brien, 2009; Rutherford et al., 2010), here we refer to these outcome probabilities as "expected value" rather than linearly transforming outcome probabilities to expected values (corresponding to −4, −1, 0, 1, 4). The assignment of the 16 face exemplars to the pairs was counterbalanced between participants. Four exemplars were not shown in the value-learning task and served as "novel" faces in the CFS task (see below). Each trial began with a 1-s blank screen with the contours only and a 1-s fixation period, followed by a pair of faces. Location of the face exemplars was randomized from trial to trial. Participants selected one of the two faces using the arrow keys, with no speed pressure. Upon selection, they received feedback ("WIN" in green font, "LOSS" in red font, or "NOTHING" in black font), together with a summary of their total monetary gains up to this trial. The feedback remained on the screen for 1.3 s. Participants were instructed to maximize their payoff. There were 600 trials, in which each combination of three pair types (rewarded, punished, neutral), two face pairs (male, female), and two stimulus locations (vertical vs. horizontal axis) occurred equally often. Trial order was randomized.

CFS Task

A few minutes after completion of the value-learning task, participants completed the CFS task, where we recorded suppression times for the faces now differing in learned expected value, plus four "novel" face exemplars that had not been used in the value-learning task (Figure 1b). Each trial started with a 1-s fixation period in which only the fusion contours and the fixation crosses were presented; the fixation crosses then turned off for 750 ms and turned on again for 200 ms to mark the beginning of a trial. CFS masks changing every 100 ms were then presented to one eye, and a face was gradually introduced to the other eye by decreasing its transparency to zero over the first second of a trial. Beginning 1 s after trial onset, the contrast of the CFS masks was linearly decreased to zero over 10 s in order to force eventual breakthrough. The face was presented until response, or for a maximum trial length of 12 s. Faces were presented in one of the four locations from the value-learning task (above, below, left, or right of fixation, selected at random for every trial). Participants were asked to press one of the four arrow keys on the

Figure 1
Schematics of the Experiments



Note. (a) In the value-learning task, participants were presented with pairs of faces, which could lead to monetary gain, loss, or no outcome. Participants selected one face from each pair. One of the faces in rewarded and punished pairs was associated with high motivational salience (probability of win or loss 80%) and the other with low motivational salience (probability of win or loss 20%). (b) Example trials from Experiment 1 (continuous flash suppression [CFS] task) and from Experiment 2 (attentional-blink [AB] localization task and AB recognition task). In CFS, participants localized a face presented in one of four locations as quickly as possible. In the AB experiments, faces (T2) were presented with a short (200 ms) or long (800 ms) lag after a (green) T1 stimulus that participants were asked to identify. In the AB-localization task, participants then indicated T2 location. In the AB-recognition task, participants indicated whether T2 was previously presented in the value-learning task ("old") or not ("new"). Note that for copyright reasons, this figure shows face images from the Karolinska face data set (Lundqvist et al., 1998) rather than from the FACES database (Ebner et al., 2010) used in the actual experiment. The face icons in this figure were adapted from images AF01NES, AF02NES, AF05NES, AF06NES, AF15NES, AM03NES, AM09NES, and AM10NES from the Karolinska face data set. See the online article for the color version of this figure.

keyboard corresponding to the four possible face locations to indicate as quickly and accurately as possible in which location a face or any part of a face became visible. For 38 participants, the CFS task consisted of 256 trials, in which all combinations of two eyes for face presentation and 16 face exemplars occurred 16 times. Trial order was randomized. Fifteen participants completed 320 trials, in which we randomly intermixed 64 trials with inverted versions of the face exemplars (rotated by 180 degrees, i.e., each of the 16 face exemplars shown two times to each eye, at a random location), and participants were informed about this additional manipulation. We included inverted faces to ensure that our CFS setup would be sufficiently sensitive to detect the well-established face-inversion effect.

Analyses

Results are shown in Figures 2, 3, 4, 5, and 6. For the value-learning task, the probability of optimal choice was calculated for 10 trial bins containing 60 trials each. For win pairs, the optimal choice was the 80%-win face. For loss pairs, the optimal choice was the 20%-loss face. For the neutral condition, choice probability of one arbitrarily selected face is plotted for comparison (Figures 2a, 4a, and 5a). Because proportional data such as choice rates or accuracy are not strictly normally distributed, descriptive statistics in the text are given as median and interquartile range, and all statistical analyses were carried out following a rationalized arcsine (RAU) transformation (where a score of 50 corresponds to 50% correct, with RAU values scaling between −23 and 123). For the CFS task trials with incorrect or no localization responses (*Mdn* = 1.2%, interquartile range [IQR] = 1.3) were excluded from all analyses. As suppression times also violate the assumption of normality, they were $\log_{10}$-transformed (Gayet & Stein, 2017) before condition means were calculated and statistical analyses were carried out. For illustration purposes and easy eyeballing of the results in standard units, $\log_{10}$-transformed suppression times were transformed back (see descriptive statistics and Figure 2b; for $\log_{10}$-transfomed suppression times, see Figure 3). All data used in the analyses reported in this article are available under https://osf.io/4dqe8/.

Statistics

We report both standard frequentist statistics and Bayes factors (BFs) calculated in JASP (JASP Team, 2020) with default prior scales (Cauchy distribution, scale .707). When frequentist statistics indicate a significant effect, the corresponding BF quantifies the evidence for the alternative hypothesis (BF_{10}); when the effect is not significant, the reported BF quantifies the evidence for the null hypothesis (BF_{01}). Following previous studies on value learning with faces, our power calculations and inferences are primarily based on frequentist statistics, with BFs providing additional information on the evidence for the null versus alternative hypotheses. For multifactorial analyses of variance (ANOVAs), we report the inclusion BF quantifying the evidence for all models containing a particular effect compared to all models without that effect. When the assumption of sphericity was violated, we report degrees of freedom and *p* values after Greenhouse–Geisser correction.

Results and Discussion

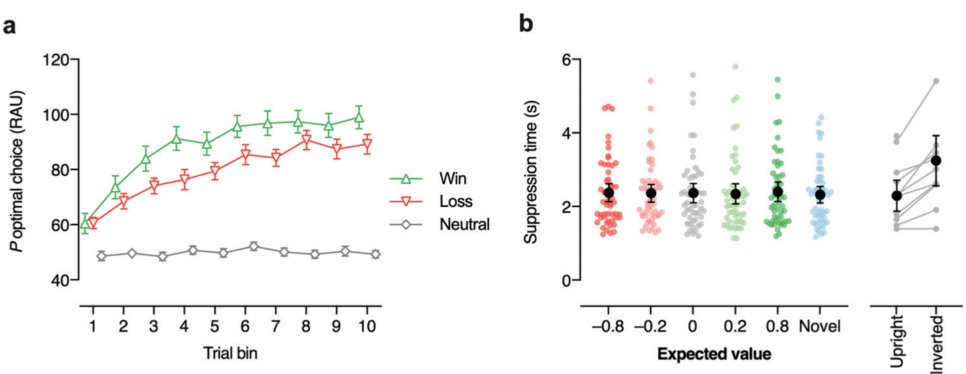
Value-Learning Task

As can be seen in Figure 2a, across win and loss pairs, probability of optimal choice increased over the 10 trial bins in a session ($F(3.99, 207.39) = 35.50$, $p < .001$, $\eta_p^2 = .41$, $BF_{10} = 1.05 \times 10^{46}$). Choices were better for win than for loss pairs ($F(1, 52) = 10.89$, $p = .002$, $\eta_p^2 = .17$, $BF_{10} = 2.28 \times 10^{19}$). The interaction between valence and trial bin was not significant ($F(4.92, 255.82) = 1.64$, $p = .15$, $\eta_p^2 = .03$, $BF_{01} = 86.19$). Performance appeared to have reached asymptote after six trials bins (of 60 trials each) for both win pairs (*Mdn* = 94.7% correct, IQR = 24.8) and loss pairs (*Mdn* = 86.4% correct, *SD* = 24.7). For both win and loss pairs, in the sixth bin, performance was significantly better than in the previous bin ($p < .05$) but did not differ significantly from the following bins ($p > .10$). Overall choice performance was similar to previous studies using comparable value-learning tasks with faces.

CFS Task

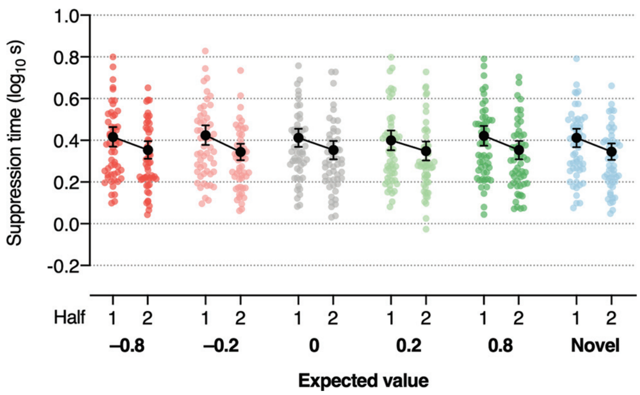
In brief, suppression times were similar for faces with different expected values, and statistical analyses did not reveal any indication of effects of valence (rewarded, punished) or motivational salience (80% vs. 20% outcome probability; see Figure 2). An ANOVA with the factors valence and motivational salience revealed no significant effects (valence, $F(1, 52) = .42$, $p = .52$, $\eta_p^2 < .01$, $BF_{01} = 5.99$; motivational salience, $F(1, 52) = .62$, $p = .43$, $\eta_p^2 = .01$, $BF_{01} = 4.11$; interaction, $F(1, 51) = .91$, $p = .34$, $\eta_p^2 = .02$, $BF_{01} = 3.55$). We carried out a set of 15

Figure 2
Results From Experiment 1 (Continuous Flash Suppression [CFS])



Note. (a) Mean probability of optimal choice in the value-learning task for 10 trial bins of 60 trials each. Error bars represent between-subjects *SE*s. Note that all proportions (optimal choice, accuracy, hit rates) are plotted as rational arcsine (RAU) scores (where a score of 50 corresponds to a proportion of 0.5, with RAU values scaling between −23 and 123). (b) Mean suppression times in the breaking CFS task for the five conditions with different expected outcome (−0.8, −0.2, 0, 0.2, 0.8) and for "novel" faces that were not shown in the value-learning task. Also shown is the face-inversion effect (difference between upright and inverted faces, $p < .001$) that was tested in a subset of 15 participants. (b) $\log_{10}$-transformed suppression times were transformed back to standard units. Every small colored (gray) circle represents a participant ($N = 53$); large black circles represent the mean and error bars the 95% CIs. See the online article for the color version of this figure.

Figure 3
Results from Experiment 1 (Continuous Flash Suppression), Shown Separately for the First and the Second Half of the Experiment



Note. Data are shown separately for the different conditions differing in expected value, plus the novel-face condition. Every small colored (gray) circle represents a participant (N = 53); large black circles represent the mean and error bars the 95% CIs. See the online article for the color version of this figure.

paired sample t tests comparing all conditions (uncorrected for multiple comparisons) to ensure that we did not miss a potential effect. However, there were no significant differences between any of the conditions, including the comparisons with novel faces (all $t(52) < 1.27$, $p > .21$, $d_z < .18$, $BF_{01} > 3.15$). Thus, there was no effect of value learning on awareness of faces in CFS. To our surprise, these data also do not replicate our previous finding of overall shorter suppression times for learned versus novel faces Stein et al. (2017).

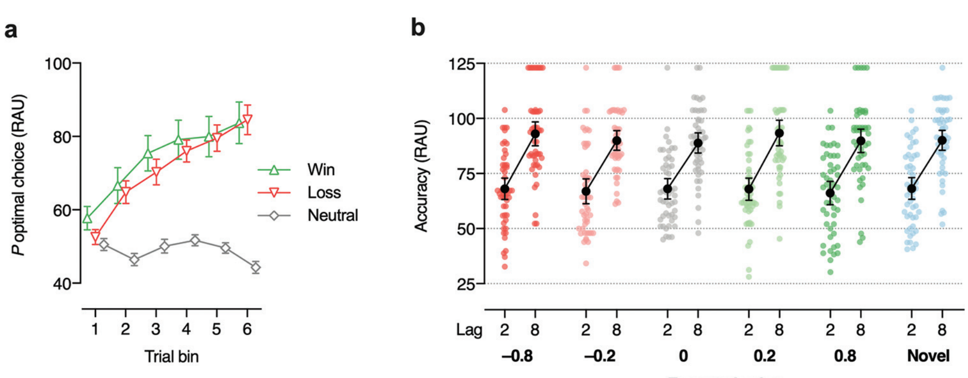
To check whether our CFS task had enough sensitivity to detect possible differences in suppression times, we measured the well-established face-inversion effect (Jiang et al., 2007; Stein, 2019; Stein et al., 2012) in a subset of 15 participants. As is commonly found, suppression times for upright faces (M = 2.29 s) were (much) shorter than for inverted faces (M = 3.24 s), with substantial evidence for an effect of inversion ($t(14) = 7.26$, $p < .001$, $d_z = 1.87$, $BF_{10} = 4.84 \times 10^3$). This demonstrates that our CFS setup was capable of detecting effects.

Finally, we compared suppression times between the first and the second half of the CFS task. This was done to check for potentially short-lived learning effects (Rothkirch et al., 2013) and to test whether overall suppression weakened over time, as is commonly found (Ludwig et al., 2013; Stein et al., 2016). As can be seen in Figure 3, while there was no evidence for effects of value learning on suppression times in either the first or in the second half of the experiment, in all conditions suppression times became shorter in the second half of the experiment (paired sample t tests, all $t(52) < 4.17$, $p < .001$, $d_z > .57$, $BF_{10} > 197.37$). Thus, suppression times for faces showed the established patterns of being shorter for upright than inverted faces and of becoming shorter over time but were not influenced by value learning.

Experiment 2: Attentional Blink (AB)

To determine whether the absence of effects in CFS reflected the perceptual nature of our task (simple localization) or properties of the method, such as CFS abolishing processing early in the visual system (Moors et al., 2017), we conducted two AB experiments. In models of consciousness, such as global neuronal work space theory (Dehaene et al., 2006), a distinction has been made between visual processing of stimuli with reduced stimulus strength (such as in CFS) versus stimuli with greater stimulus strength under limited attention (such as in the AB), with more extensive processing taking place in the latter case. In Experiment 2a (AB-localization), participants localized a face that followed an

Figure 4
Results From Experiment 2a (AB-Localization)



Note. (a) Mean probability of optimal choice in the value-learning task for six trial bins of 60 trials each. Error bars represent between-subjects *SE*s. (b) Face localization accuracy in the AB-localization task, shown separately for Lag 2 and Lag 8, for the five conditions with different expected outcome (−0.8, −0.2, 0, 0.2, 0.8) and for "novel" faces that were not shown in the value-learning task. Every small colored (gray) circle represents a participant (N = 49); large black circles represent the mean and error bars the 95% CIs. AB = attentional-blink; RAU = rational arcsine. See the online article for the color version of this figure.

attention-demanding first target with a short or long lag. Similar to the CFS experiment, the localization task did not require memory retrieval. If acquired value influenced basic face perception and awareness, we would expect an effect on overall localization performance. If acquired value influenced attention, we would expect differential effects for the two lags (i.e., influence on AB magnitude), with a reduced or eliminated AB for win-associated faces (Raymond & O'Brien, 2009). Experiment 2b was a conceptual replication of Raymond and O'Brien's (2009) study, where participants indicated whether an AB sequence had previously been presented in the value-learning task. If acquired value modulated memory for faces, we would expect an effect on overall recognition accuracy. If acquired value also influenced attention in this task, as reported by Raymond and O'Brien (2009), we would expect an effect on AB magnitude, with a smaller AB for win-associated faces.

Method

Participants

One hundred participants, most of them undergraduate psychology students, were recruited through the University of Amsterdam participant pool. Informed consent was obtained following a protocol approved by the University of Amsterdam local ethics committee. Half of the participants were assigned to the AB-localization task (Experiment 2a) and half to the AB-recognition task (Experiment 2b). A total of 4 of the 100 participants were excluded due to poor overall performance, indicating failure to follow instructions. In the AB-localization experiment, one participant whose overall localization accuracy was below the chance level of 50% was excluded. In the AB-recognition experiment, three participants whose overall recognition sensitivity was below the chance level of $d' = 0$ were excluded. The final samples consisted of 49 participants in the AB-localization experiment (2 female, mean age 24.3 years, $SD = 8.4$) and 47 participants in the AB-recognition experiment (31 female, mean age 23.0 years, $SD = 6.4$).

Display, Apparatus, and Stimuli

The overall setup was similar to Experiment 1, except that participants viewed the screen binocularly from a free viewing distance of approximately 70 cm, and the contour in which stimuli were presented was displayed in the center of the screen (Figure 1b). As we used stimuli of identical pixel dimensions in all experiments, depending on participants' free viewing distance, the retinal projections of the stimuli in the AB experiment were slightly larger than in Experiment 1. Stimuli were the same photographs as in Experiment 1. For the AB-recognition task, we added six faces that served as additional "novel" stimuli, such that for every participant, there were 12 "old" face exemplars seen in the value-learning task and 10 "novel" face exemplars. The assignment of face exemplars was counterbalanced between participants. For the AB experiments, 154 scrambled distracters were generated by dividing the face stimulus ovals into grids consisting of 16 or 20 rectangles of different sizes and randomly rearranging these rectangles. As a first attention-demanding target (T1), we created 88 stimuli that consisted of a random arrangement of differently sized circles or rectangles. These were then cut to correspond to the face ovals and displayed through the green RGB channel only (rendering T1 salient in the context of gray faces and distracters).

Value-Learning Task

The value-learning task was similar to Experiment 1, with the following exceptions. Face pairs were shown only in the left or right location (corresponding to the two locations in the AB-localization task), and we reduced the number of trials to 360, as Experiment 1 had indicated that performance reached asymptote after six trial bins of 60 trials each.

AB-Localization Task

Each trial started with a 1-s fixation, which then turned off for 500 ms to mark the beginning of the RSVP sequence. Three different streams of 24 randomly selected scrambled distracters changing every 100 ms were presented in the left, right, and central location within the contour (Figure 1b). After the presentation of 7–11 distracters (selected at random), T1 (green circles or diamonds) was presented in the central stream; the face stimulus followed after 1 or 7 distracters in the left or right stream (resulting in T1–T2 SOAs of 200 and 800 ms, corresponding to "Lag 2" and "Lag 8" conditions). At the end of the stimulus presentation sequence, participants first indicated T1 identity using the "1" (circles) and "2" (rectangles) keys and then indicated face location using the left and right arrow keys. In both AB-localization and AB-recognition, instructions emphasized the importance of getting the T1 identity right, and participants were instructed to respond as accurately as possible, without speed pressure. The AB-localization task consisted of 384 trials, in which all combinations of two lags, two face locations, two T1 identities, and 16 face exemplars occurred six times. Trial order was randomized.

AB-Recognition Task

Each trial started with a 1-s fixation, which then turned off for 500 ms to mark the beginning of the stimulus presentation sequence. All stimuli were presented in the center of the central contour (Figure 1b). T1 was presented for 100 ms, followed by a scrambled distracter for 100 ms and a blank contour for 100 ms ("Lag 2") or for 700 ms ("Lag 8"), followed by a face stimulus for 100 ms and another scrambled distracter for 100 ms. Participants then indicated T1 identity using the "1" (circles) and "2" (rectangles) keys and then whether the face was "old" (presented in the preceding value-learning task) or "new" (not presented in the value-learning task) using the left and right arrow keys. There were 440 trials, in which all combinations of two lags, two T1 identities, and 22 face exemplars occurred five times. Trial order was randomized.

Analyses

For the value-learning task, analyses were the same as in Experiment 1. For the AB tasks, only trials with correct T1 identification were included in the analyses (AB-localization task, $Mdn = 95.1\%$ correct, IQR = 4.0; AB-recognition task, $Mdn = 88.2\%$ correct, IQR = 10.0). All statistical analyses of proportions of correct responses were carried out on RAU scores, while descriptive statistics in the text refer to the nontransformed proportions. In the AB-localization task, accuracy represents a criterion-free estimate of localization performance (chance level 50% correct). The AB-recognition task, in contrast, is a "yes/no" task, and we report proportion correct for the different conditions (for old faces, this corresponds to the hit rate; for new faces, this corresponds to the correct-rejection rate). Although a previous study reported d' for old faces in this recognition task (Raymond & O'Brien, 2009), d' for the different conditions would be based on identical false-alarm rates (new faces did not differ with regard to expected value), and thus differences between value conditions can, by definition, only influence the hit rate, so that d' for the different conditions would not represent a criterion-free index of sensitivity but would be equivalent to the hit rates reported here.

Results and Discussion

Value-Learning Task

As can be seen in Figure 4a (AB-localization) and Figure 5a (AB-recognition), value learning was similar for the two experiments, and we collapsed the data from the 96 participants for the following analyses. Across win and loss pairs, probability of optimal choice increased over the six trial bins in a session ($F(3.04, 288.93) = 58.89$, $p < .001$, $\eta_p^2 = .38$, $BF_{10} = 4.45 \times 10^{35}$), and choices were better for win than for loss pairs ($F(1, 95) = 6.14$, $p = .015$, $\eta_p^2 = .06$, $BF_{10} = 3.21 \times 10^4$). The interaction between valence and trial bin was not significant ($F(3.42, 324.69) = .85$, $p = .48$, $\eta_p^2 < .01$, $BF_{01} = 241.04$). Overall performance after six trial bins for win pairs (*Mdn* = 91.6% correct, IQR = 45.1) and loss pairs (*Mdn* = 81.8% correct, IQR = 30.3) was similar to Experiment 1 (independent samples *t* tests, both $t(147) < 1.54$, $p > .12$, $BF_{01} > 1.86$), and there was substantial variation between participants.

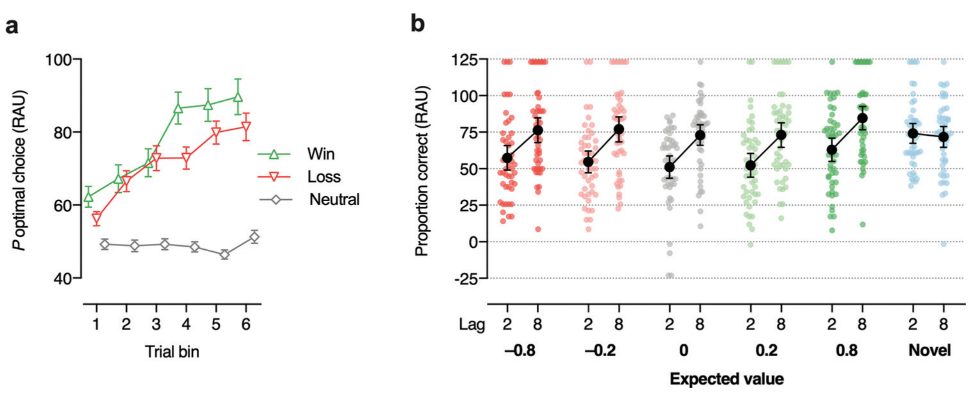
AB-Localization Task

Figure 4b shows face-localization accuracy for the different conditions and lags. A three-way repeated-measures ANOVA including lag (2 vs. 8) and the four key conditions that differed in valence and motivational salience (win vs. loss, 80% vs. 20% outcome probability) revealed a significant main effect of lag ($F(1, 48) = 131.80$, $p < .001$, $\eta_p^2 = .73$, $BF_{10} = 1.14 \times 10^{51}$), with better performance at Lag 8 (*Mdn* = 88.1% correct, IQR = 12.8) than at Lag 2 (*Mdn* = 64.2% correct, IQR = 21.4) and a two-way interaction between valence and motivational salience ($F(1, 48) = 5.19$, $p = .027$, $\eta_p^2 = .10$, but $BF_{10} = 1.02$), but no other significant effects (all $F < .75$, $p > .39$, $\eta_p^2 < .02$, $BF_{01} > 3.67$). The two-way interaction reflected an unexpected pattern of results. For loss pairs, performance tended to be better for high-probability faces than for low-probability faces, whereas for win pairs, performance tended to be better for low-probability faces than for high-probability faces (Figure 4b). Because the effect was not in line with our hypotheses or previous findings (Raymond & O'Brien, 2009) and considering that the Bayes factor for this interaction indicates that the null hypothesis is equally likely as the alternative hypothesis, we did not further unpack this effect with follow-up *t* tests. A set of six paired sample *t* tests comparing localization performance between the long and the short lag for every condition (uncorrected for multiple comparisons) revealed significantly better performance at Lag 8 than at Lag 2 for all conditions (all $t(45) > 7.66$, $p < .001$, $d_z > 1.09$, $BF_{10} > 1.51 \times 10^7$). However, AB magnitude did not differ significantly between conditions (as indicated by the absence of significant interactions with lag). Together, these results provide no evidence for a reduced AB for win-associated faces or for better localization of faces with high motivational salience.

AB-Recognition Task

Analogous analyses carried out on the hit rates for the four key conditions in the AB-recognition task (see Figure 5b) revealed a significant main effect of lag ($F(1, 46) = 95.02$, $p < .001$, $\eta_p^2 = .67$, $BF_{10} = 1.04 \times 10^{17}$), with higher hit rates at Lag 8 (*Mdn* = 73.1%, IQR = 25.6) than at Lag 2 (*Mdn* = 55.4%, IQR = 33.4), a

Figure 5
Results From Experiment 2b (AB-Recognition)



Note. (a) Mean probability of optimal choice in the value-learning task for six trial bins of 60 trials each. Error bars represent between-subjects *SE*s. (b) Proportion of correct responses in the AB-recognition task, shown separately for Lag 2 and Lag 8, and for the five conditions with different expected outcome (−0.8, −0.2, 0, 0.2, 0.8). For these "old" faces that were shown in the value-learning task, proportion correct reflects the hit rate. For "novel" faces that were not shown in the value-learning task, proportion correct reflects the correct rejection rate. Every small colored (gray) circle represents a participant (*N* = 47); large black circles represent the mean and error bars the 95% CIs. AB = attentional-blink; RAU = rational arcsine. See the online article for the color version of this figure.

significant effect of motivational salience ($F(1, 46) = 6.46$, $p = .014$, $\eta_p^2 = .12$, $BF_{10} = 6.40$), with higher hit rates for faces leading to an outcome with 80% probability (*Mdn* = 69.6%, IQR = 31.4) than for faces leading to an outcome with only 20% probability (*Mdn* = 62.6%, IQR = 25.9), and a significant interaction between valence and motivational salience ($F(1, 46) = 5.22$, $p = .027$, $\eta_p^2 = .10$, but $BF_{10} = 2.29$), but no other significant effects (all $F < .71$, $p > .40$, $\eta_p^2 < .02$, $BF_{01} > 4.32$). Although Bayes factor revealed only anecdotal evidence for the valence-by-salience interaction, from Figure 5b it is clear that the effect reflected particularly high hit rates for high-probability win-associated faces. For loss-associated faces, there was no significant difference between high- and low-probability faces ($t(46) = .22$, $p = .83$, $d_z = .03$, $BF_{01} = 6.18$). For win-associated faces, by contrast, hit rates were significantly higher for high-probability faces than for low-probability faces ($t(46) = 3.80$, $p < .001$, $d_z = .55$, $BF_{10} = 63.36$). Hit rates for high-probability win-associated faces were also significantly higher than for neutral and low-probability loss-associated faces (both $t(46) > 3.48$, $p < .002$, $d_z > .42$, $BF_{10} > 5.84$) and tended to be somewhat higher than for high-probability loss-associated faces ($t(46) = 2.30$, $p = .026$, $d_z = .34$, but $BF_{10} = 1.70$). These results indicate better recognition memory for faces with high motivational salience, and this effect was particularly pronounced for win-associated faces.

Finally, paired sample *t* tests revealed a significant AB (higher hit rates at Lag 8 than at Lag 2) for all five "old" conditions (faces presented in the value-learning task, all $t(46) > 5.57$, $p < .001$, $d_z > .81$, $BF_{10} > 1.34 \times 10^4$). For "new" faces (faces not presented in the value-learning task), correct rejection rates did not differ significantly between Lag 8 and Lag 2 ($t(46) = .78$, $p = .44$, $d_z = .11$, $BF_{01} = 4.47$). Overall mean recognition d' was .87 (*SD* .68) at Lag 2 and 1.35 (*SD* .81) at Lag 8, similar to the AB-recognition study by Raymond and O'Brien (2009), but AB magnitude did not differ between conditions (as indicated by the absence of significant interactions with lag). In summary, the AB-recognition experiment revealed overall better recognition memory for high-probability win-associated faces but no evidence for a modulation of the AB by valence or motivational salience.

Overview of Key CFS and AB Effects

To facilitate interpretation and for straightforward comparison with a subgroup analysis of particularly good value learners (see below), we calculated difference scores reflecting the key effects of motivational salience and affective value from the CFS and AB data. The salience effect was calculated as the difference between low- and high-probability faces, the gain effect as the difference between win-associated and neutral faces, and the loss effect as the difference between loss-associated and neutral faces. We also calculated a high-gain and a high-loss effect as the difference between win/loss-associated faces with high outcome probability and neutral faces. Figure 6 shows these key effects, plotted such that positive values indicate an effect in the predicted direction (e.g., a positive gain effect in the CFS experiment would reflect shorter suppression times for win-associated faces than for neutral faces and higher accuracy/hit rates for win-associated faces than for neutral faces in the AB experiments). For the AB experiments, we calculated both overall effects across Lag 2 and Lag 8, as well as blink effects, for which we contrasted the AB size (Lag 8 minus Lag 2) between conditions (e.g., a positive gain blink effect would reflect a smaller AB for win-associated faces than for neutral faces).

To test for effects in the predicted direction, all effects were tested against zero with one-sided *t* tests. For CFS, none of the effects were significant, with strong evidence for the null hypothesis (all $t(52) < .13$, $p > .45$, $d_z < .02$, $BF_{01} > 6.04$). For overall accuracy in the AB-localization experiment, there were no significant effects either, but the data were more variable, resulting in weaker support for the null hypothesis (all $t(48) < 1.09$, $p > .14$, $d_z < .16$, $BF_{01} > 2.17$). For overall hit rates in the AB-recognition experiment, there were significant effects of salience ($t(46) = 2.88$, $p = .003$, $d_z = .42$, $BF_{10} = 11.81$), gain ($t(46) = 1.90$, $p = .032$, $d_z = .28$, but $BF_{10} = 1.59$), and high gain ($t(46) = 3.91$, $p < .001$, $d_z = .57$, $BF_{10} = 170.16$), but no other significant effects (both $t(46) < 1.13$, $p > .13$, $d_z < .17$, $BF_{01} > 2.02$). These results confirm our previous analyses: While there was no effect of value learning on suppression times and face localization, recognition performance was better for faces with high motivational salience, particularly for high-probability win-associated faces. In the AB experiments, there was no evidence that the magnitude of the blink was influenced by value learning (all $t < .97$, $p > .16$, $d_z < .15$, $BF_{01} > 2.45$). Thus, in the AB-recognition experiment, motivational salience and reward boosted overall recognition, but there was no evidence for greater attentional priority of motivationally salient or rewarded faces.

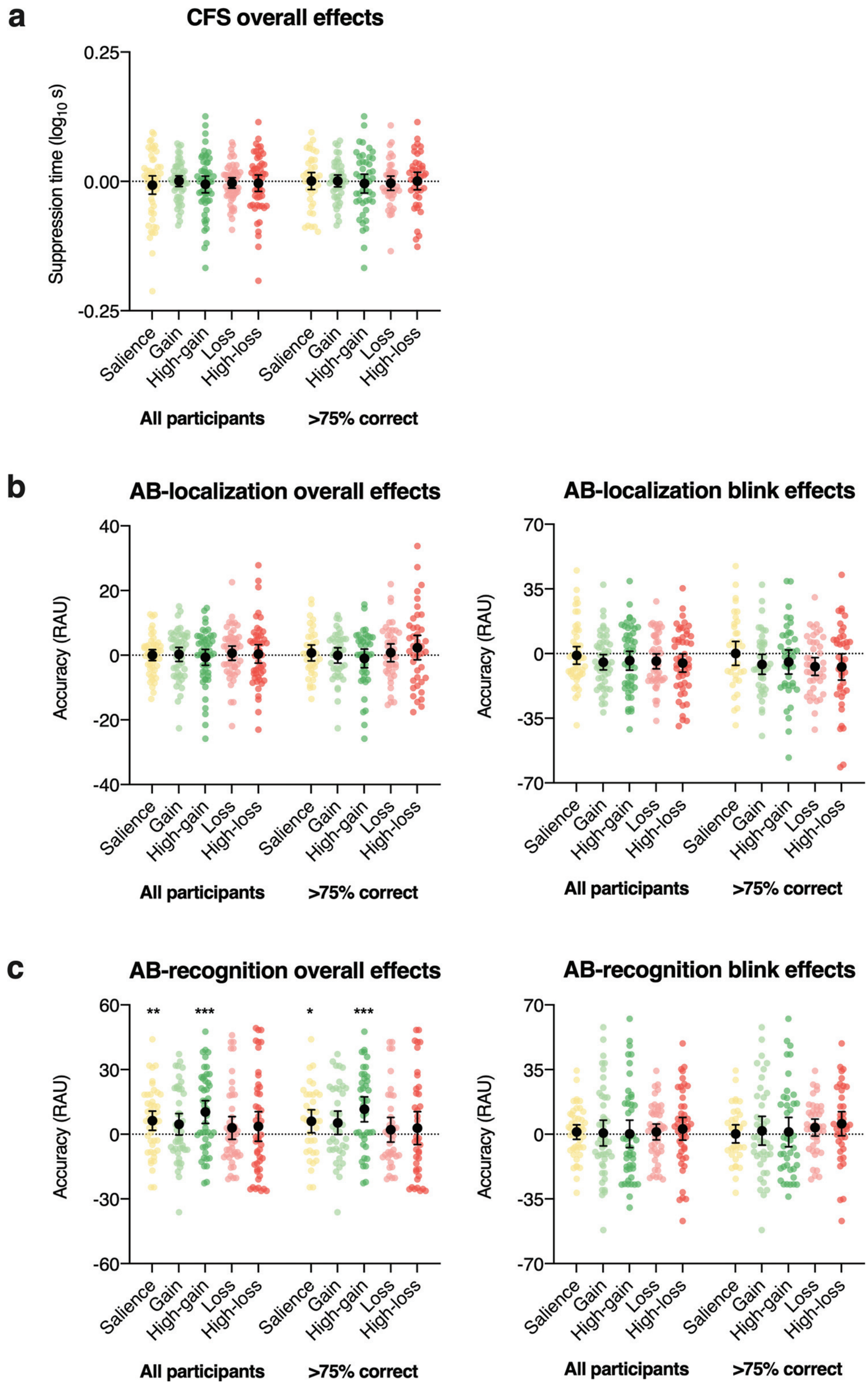
Finally, in all experiments, there was substantial variability in value learning. One concern is that only particularly good learners might have shown an effect. To address this possibility, we considered correlating performance in the value-learning task with the CFS and AB effects. However, for many participants value learning was at ceiling (in particular for win-associated face pairs). We therefore calculated all key effects separately for those participants who demonstrated learning defined as performing above a certain (arbitrary) criterion, following Rutherford et al. (2010). We set this criterion to choosing the optimal stimulus (high-probability win face [.8], low-probability loss face [−.2]) on more than 75% of the trials in the last bin of the value-learning task. If the respective criterion was achieved for only one of the face pairs, only this pair was included in the analyses. Figure 6 shows all key effects separately for those participants who performed above the criterion (right panels). In brief, results for these subgroups of particularly good learners were virtually the same as for the whole group, with no evidence for stronger effects of motivation or valence in any of the experiments.

General Discussion

Although it is widely believed that emotional and motivational value can influence perception of social signals such as faces, there is little unequivocal empirical support for this idea. For example, a recent meta-analysis compared the effects of different emotional stimuli and found that only fearful faces elicited reliable effects on visual perception and attention across a range of different experimental paradigms, such as breaking CFS, binocular rivalry, and attentional capture (Hedger et al., 2016). However, fearful faces differ from nonemotional stimuli in terms such as local contrast (Yang et al., 2007) and effective contrast (Hedger et al., 2015), such that effects could reflect differences in low-level properties rather than genuine influences of emotion on perception. To rule

Figure 6

Overview of the Key Effects From (a) CFS, (b) AB-Localization, and (c) AB-Recognition



Note. Shown are difference scores for overall suppression times (CFS), accuracy (AB-localization), and hit rates (AB-recognition). See text for calculation of effects. Effects are plotted such that positive values indicate an effect in the

(Continued on next page)

out such low-level explanations, here we associated faces with different affective and motivational value and measured effects on visual awareness, attention, and memory. Following the value-learning procedure, we found that participants were more likely to recognize faces with high motivational salience, but we did not obtain effects on awareness in CFS (Experiment 1), RSVP (Experiment 2a), or attentional priority during the AB (Experiments 2a and 2b), suggesting that acquired affective and motivational value affects face perception only at later stages associated with memory.

In all experiments, results from the value-learning task demonstrated successful learning for both win- and loss-associated faces. Although there was large variability between participants, restricting the analyses to the subset of particularly good learners did not change the pattern of results. Consistent with previous studies that used affective-learning procedures with faces, in the CFS experiment there was no evidence for effects of value learning on awareness of faces. The strong inversion effect we obtained in a subset of participants demonstrated that our setup was sufficiently sensitive to detect effects. The results from the AB-localization experiment provided further support that basic perception, as measured with localization tasks that were fully orthogonal to the value-learning manipulation, is not influenced by learned emotion and motivation. We recently adopted the same modified RSVP procedure with three parallel streams to measure localization of upright and inverted faces and obtained strong inversion effects similar to CFS with this method (Stein & Peelen, 2021), indicating that this AB-localization task is, in principle, capable of detecting effects on perception. Together, the results from the CFS and AB-localization experiment indicate that for faces, acquired value does not influence perception and attention.

Both the AB-localization and AB-recognition experiments produced strong AB-like effects of lag (long vs. short lag). Note that both experiments involved a task set switch from T1 (discrimination of circles vs. squares) to T2 (face localization or recognition). It is thus possible that lag effects reflected task switch costs, rather than limits of temporal attention per se, as measured in AB paradigms that involve no task set switch (Kelly & Dux, 2011; Potter et al., 1998). However, there is evidence that lag effects in paradigms with and without task set switch measure similar attentional mechanisms (Dale et al., 2013). Furthermore, neither our AB experiments nor the original AB study by Raymond and O'Brien (2009) included a condition in which participants were instructed to ignore T1. We can therefore not exclude the possibility that lag effects may have (partly) been caused by stimulus-related factors (e.g., forward masking), rather than exclusively by attentional limitations. It is also known that a switch in target location, as in our AB-localization experiment, affects the temporal dynamics of the AB (e.g., it eliminates so-called lag-1 sparing; Visser et al., 1999). We decided to use a localization task (rather than, e.g., a detection task) to match stimulus presentation and task requirements with the CFS experiment and to derive a criterion-free (forced-choice) measure of perceptual sensitivity (as opposed to, e.g., hit rates in a detection task that are susceptible to response criteria). Our measure of localization accuracy ruled out influences from postperceptual processes (e.g., confidence, decision-making) and thus served as an index that could have provided unequivocal evidence for top-down effects on perception.

Our conclusions are naturally limited to the particular stimuli and value-learning task adopted in our study. As such, they do not contradict effects of emotion on perception obtained with simple stimuli such as colors and gratings following classical fear conditioning procedures. It is possible, for example, that learning signals can modulate neural representations of comparably simple stimuli in early visual cortex (Padmala & Pessoa, 2008), leading to enhanced perception and attention (Gayet et al., 2016), while they do not affect downstream visual areas representing more complex stimuli such as objects and faces. Similarly, it is possible that the present value-learning task failed to induce sufficiently strong learning signals that would have penetrated visual perception. Pairing stimuli with electrical shocks arguably represents a more powerful manipulation than pairing stimuli with small amounts of monetary gain or loss. However, as we rarely encounter stimuli in our daily lives that are paired with unconditioned stimuli such as electric shocks (or so we hope), our value-learning task with faces may represent a more ecologically valid test of emotional and motivational influences on perception. Together with previous failures to obtain effects of affective learning on basic perception of faces, our findings place an upper boundary on the effects of affective learning on perception and attention.

The results from the AB-recognition experiment, which was a conceptual replication of Raymond and O'Brien (2009), came as a surprise. While we replicated overall better recognition of faces that had greater motivational relevance, we did not find a modulation of the AB or a reduced AB for win-associated faces. There are several differences between our implementation of the AB-recognition task and the study by Raymond and O'Brien (2009) that may account for the different pattern of results. While we used photographs of real faces, Raymond and O'Brien (2009) used computer-generated faces. It is possible that in our study, participants attended to features of faces (such as the eyebrows) that were informative in the value-learning procedure, and a putative enhancement of these features following the choice game did not influence perception or attention in our CFS and AB tasks. Furthermore, Raymond and O'Brien's (2009) participants received additional auditory feedback (beeps) in the choice game, perhaps providing an additional learning signal that was absent in our study. Finally, as performance in the choice game reached asymptote in the CFS experiment after six bins, we shortened the value-learning procedure for the

Figure 6 ***(Continued)***

predicted direction (e.g., a positive gain effect in the CFS experiment would reflect shorter suppression times for win-associated faces than for neutral faces and higher accuracy/hit rates in the AB experiments). For the AB-experiments, also blink effects are shown, where positive values would reflect a reduced AB magnitude in the predicted direction. Every small colored (gray) circle represents a participant, large black circles represent the means, and error bars show 95% CIs. Asterisks indicate significant *t* tests (two-tailed for plotting) against chance: * $p < .05$. ** $p < .01$. *** $p < .001$. AB = attentional-blink; CFS = continuous flash suppression; RAU = rational arcsine. See the online article for the color version of this figure.

AB experiments, resulting in fewer trials compared to Raymond and O'Brien's (2009) study. However, as performance in the value-learning tasks was similar to previous studies, these speculations represent post hoc explanations for our findings and are not directly supported by data.

In support of a modular view of the mind, Firestone and Scholl (2016) concluded that top-down effects on vision have not been convincingly established and provide a list of six pitfalls that undermine such claims in many studies. The present results, together with previous studies using similar affective-learning procedures with faces, highlight several of their pitfalls. One pitfall pointed out by Firestone and Scholl (2016) includes conflating "top-down effects with low-level differences," as is common in studies using stimuli with intrinsic emotional value such as fearful faces. Other pitfalls include conflating "perception versus judgment," "perception versus demand and response bias," and "memory and perception" in dependent measures collected in such studies. These issues are reflected in the criterion-sensitive measure of memory adopted in the AB-recognition experiment. Future studies investigating the effect of acquired emotional-motivational value on visual perception and memory need to carefully distinguish between these factors. For now, our results suggest that effects of value learning on face perception are limited to dependent measures that reflect memory and are sensitive to criterion effects, and they do not provide support for the idea that motivation and emotion influence basic perception.

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Received October 5, 2020
Revision received January 10, 2021
Accepted February 20, 2021 ■