The Influence of Facial Blushing and Paling on Emotion Perception and Memory

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Abstract

Emotion expressions facilitate interpersonal communication by conveying information about a person's affective state. The current work investigates how facial coloration (i.e., subtle changes in chromaticity from baseline facial color) impacts the perception of, and memory for, emotion expressions, and whether these depend on dynamic (vs. static) representations of emotional behavior. Emotion expressive stimuli that either did or did not vary in facial coloration were shown to participants who were asked to categorize and rate the stimuli's intensity (Exps. 1 & 2), as well as recall their degree of facial coloration (Exps. 3 & 4). Results showed that changes in facial coloration facilitated emotion categorization accuracy in dynamic (Exp. 1) but not static expressions (Exp. 2). Facial coloration further increased perceived emotion intensity, with participants misremembering the coloration of both dynamic and static expressions differently depending on emotion category prototype (Exps. 3 & 4). Together, these findings indicate that facial coloration conveys affective information to observers and contributes to biases in how emotion expressions are perceived and remembered.

Keywords: facial coloration, face perception, emotion, memory, dynamic.

The Influence of Facial Blushing and Paling on Emotion Perception and Memory

Reliably detecting and interpreting others' emotions is critical to survival and social well-being (Keltner, Haidt, & Shiota, 2006). While most research on emotion expressions has focused on facial-muscular configurations (often labeled as facial Action Units, AUs; Ekman, 1993), recent research suggests that facial coloration (i.e., subtle changes in skin chromaticity from baseline skin color, such as blushing or pallor) likewise functions as an emotion-expressive feature. Faces regularly change color with emotion due to corresponding fluctuations in cardiovascular activity (e.g., peripheral vasodilation and vasoconstriction; Benitez-Quiroz, Srinivasan, & Martinez, 2018; Drummond & Quah, 2001) and light-absorptive properties of hemoglobin interacting with the optics of the skin (Changizi, Zhang, & Shimojo, 2006). This phenomenon naturally occurs in spontaneous or felt expressions of emotion that involve peripheral blood flow reactivity, but is often not captured in posed expressions due to their instructed nature (see Scherer & Bänziger, 2010; Krumhuber, Skora, Küster, & Fou, 2017). While it is evident that facial coloration conveys emotional information, questions remain about the extent to which facial coloration is used in emotion processing. Specifically, we explore whether facial coloration influences emotion categorization accuracy and intensity judgments of facial expressions (perceptual processing), whether recall of facial coloration is biased by emotion category (memory processing), and whether these influences depend on dynamic representations of emotion (temporal processing).

Facial coloration has been shown to influence a range of social perceptions, including perceived attractiveness, health, dominance, sex, and emotion (for a review, see Thorstenson, 2018). In the domain of emotion perception, recent research has demonstrated that facial coloration is used to infer emotion categories from neutrally-expressive faces (Thorstenson et al., 2018), and facilitates perceptions of explicitly-labelled emotion expressions (Benitez-Quiroz et al., 2018). In this context, facial redness has been shown to facilitate perceptions of anger specifically (Minami et al., 2018; Nakajima et al., 2017; Peromaa & Olkkonen, 2019; Thorstenson et al., 2019; Young et al., 2017).

Previous research has suggested that facial color-emotion associations might be consistent with how face color changes during emotion expression, based on physiological models of emotion (Thorstenson et al., 2018). For example, redder faces are likely associated with anger because people's faces actually tend to become redder when angry. This implicitly suggests that memory processes are involved, such that facial color information is perceived, interpreted, and stored in memory (see Schloss, 2018, for a similar account of color-concept associations more broadly). While accurate memory for facial features presumably informs face perception (Tong & Nakayama, 1999), it has been demonstrated that face perception and memory are malleable and subject to biases (Hugenberg & Sacco, 2008). For instance, social categories of a target's face can provoke assimilation of the face to a categorical prototype, which influences how it is perceived and remembered (Corneille, Huart, Becquart & Brédart, 2004; Hugenberg, Young, Sacco, & Bernstein, 2011). Specifically, faces are remembered as looking more prototypical of the category prototype than they objectively are (Huart, Corneille, & Becquart, 2005; Wang, Guinote, & Krumhuber, 2018). Emotion expressions are often represented as categorical prototypes, i.e., stereotypical emotion terms like 'anger' and 'fear' reflect cognitive representations of emotion in memory and language (Shaver, Schwartz, Kirson, & O'Connor, 1987). These prototypes contain associative links with facial coloration; for example, anger is associated with increased facial redness, while sadness is associated with decreased facial redness (Thorstenson et al., 2018). Thus, it is reasonable to expect that this assimilation process also occurs in the recall of facial coloration for emotion-expressive faces. In other words, facial expressions might be misremembered as having facial color features that are more prototypical of the emotion category. The current work tests this hypothesis by presenting emotion expressive faces and subsequently measuring the recall of facial color.

Facial color changes transiently over time with emotion expression (Cooper & Gerlach, 2013), and the perception of subtle facial color differences critically relies on a comparison between a baseline referent and the changing facial color (Changizi et al., 2006). Likewise, there is an emerging line of research demonstrating that dynamic (i.e., changing over time) displays facilitate emotion detection, accuracy, and processing, relative to static ones (e.g., Ambadar, Schooler, & Cohn, 2005; Wehrle, Kaiser, Schmidt, & Scherer, 2000, for a review see Krumhuber, Kappas, & Manstead, 2013; Krumhuber & Skora, 2016). This is likely because social targets in the natural environment express emotions that change transiently over time. Consequently, incorporating this dynamic aspect better captures the complexity of emotion expressions. Therefore, it seems prudent to utilize dynamic expressive stimuli to investigate the influence of changing facial color on emotion recognition. However, to our knowledge, investigations of dynamic displays of facial color have yet to be conducted. In the current work, we test the influence of facial color on emotion recognition using both dynamic and static emotion expressive stimuli.

Across four experiments, we examined the influence of facial color on emotion perception and memory. In Experiment 1, participants were briefly presented with two versions of dynamic facial expressions (color-invariant, unmanipulated vs. color-variant, manipulated to change facial color) and subsequently judged which emotion expression was being displayed, along with its perceived intensity. We expected that color-variant expressions of emotion would facilitate emotion perception (i.e., higher accuracy and perceived intensity), relative to color-invariant expressions. In Experiment 2, we tested the same hypothesis, but used static rather than dynamic stimuli. In Experiment 3, participants were presented with dynamic expressions of emotion and, following a short break, were asked to recall the faces from a set of stimuli ranging in facial color. We expected that memory for facial coloration would be biased consistent with the emotion category prototype. In Experiment 4, we tested the same hypothesis, but instead initially presented static rather than dynamic emotion expressions.

For each experiment, all data exclusions, manipulations, and variables analyzed are reported, and data collection was completed prior to analysis. Each participant only participated in one of the experiments. All analyses include participants with color-normal vision assessed by both self-report and a short version of the Ishihara test at the end of the experiment. Participants who reported or demonstrated a color vision deficiency were excluded from analyses a priori. In each experiment, sample size (target $n = 90$) was determined a priori via power analysis (targeting 80% power to detect a main effect of color with Cohen's $d = .30$ at $p < .05$), which we exceeded in each experiment due to participant availability (Exp. 1 $n = 132$; Exp. 2 $n = 119$; Exp. 3 $n = 138$; Exp. 4 $n = 145$).

Experiment 1

In Experiment 1, we tested whether the facial coloration of dynamic emotion expressions influenced emotion categorization accuracy and perceived emotion intensity. We hypothesized that color-variant (i.e., manipulated to change color) emotion expressions would be categorized with greater accuracy than color-invariant (i.e., unmanipulated) expressions. We also predicted that color-variant expressions would be perceived as more intense than color-invariant expressions.

Method

Participants. One-hundred-thirty-two (100 female; M_{age} = 19.88, SD_{age} = 1.06) undergraduate students participated in the experiment in exchange for course credit. Two participants reported having a color vision deficiency and were removed from subsequent analyses.

Stimuli. We selected videos of 4 target identities (2 male and 2 female Caucasian individuals), each displaying 6 different high-intensity emotions (anger, disgust, fear, happiness, sadness, surprise) from the Amsterdam Dynamic Facial Expression Set – Bath Intensity Variations (ADFES-BIV; van der Schalk, Hawk, Fischer, & Doosje, 2011; Wingenbach, Ashwin, & Brosnan, 2016). The videos featured the targets displaying each emotion, from neutrally expressive to maximally expressive over the course of 1 second. An independent analysis indicated that the original videos did not substantially change in facial color over the course of the video ($M_{\Delta a*}$ = 0.337, $M_{\Delta b*}$ = 0.636, both of which are below detection thresholds for general color perception and color perception for faces; see Thorstenson 2018). These original, unmanipulated videos were used as the color-invariant stimuli in the current experiment.

An additional set of color-variant videos was created by manipulating the facial color of every frame of each video in a direction dependent on the emotion category. Past research (Thorstenson et al., 2018) found that people associate anger, happiness, and surprise with greater facial redness, yellowness, or both. Hence, we manipulated the expressions of these emotions in a way that facial redness and yellowness increased over time, thereby referring to this group of emotions with higher facial coloration as “blushing emotions”. Conversely, disgust, fear, and sadness have shown to be associated with decreased facial redness, yellowness, or both. We thus manipulated expressions of these emotions in a way that facial redness and yellowness decreased over time, thereby referring to this group of emotions with lower facial coloration as “paling emotions”.

The facial color manipulations were conducted in MATLAB using CIELAB colorspace: A visual space that represents the human perception of color along 3 continuous, orthogonal axes (L* - lightness dimension; a* - redness dimension; b* yellowness dimension; Fairchild, 2013). MATLAB was used to either increase or decrease the facial redness (in CIELAB a*) and facial yellowness (in CIELAB b*) for each pixel of each frame (25 frames per video). Photoshop was employed to create face-shaped masks for each frame to ensure that the color change only occurred across the skin areas of the face (excluding hair, eyes, mouth, and background). The videos either increased or decreased in facial redness and yellowness by +/- 5 units from the original face color linearly across the entire video sequence. These final color manipulated videos were used as the color-variant stimuli in the current experiment (see Figure 1 for an example of the stimuli).

Procedure. Participants completed the experiment on a BenQ 24-inch HD LED Color Certified monitor. An Xrite i-one pro spectrophotometer was used to color-calibrate the display (achieved monitor specifications were D65, x = .313, y = .329, Y = 120 cd/m^2). The viewing distance was approximately 55cm and the viewing angle approximately 0° - 15°. The display background was black and the monitor contained a black light shade. The room was dimly lit. E-Prime software was used to program and present the experiment.

Participants were instructed that they would be viewing a series of videos of people expressing various emotions, and that they would be asked to categorize and rate the intensity of each emotion. For each trial, a fixation cross was presented on the screen for 1s, followed by the onset of an emotion expression video, which played for 1s. The video automatically disappeared after offset, and participants were asked to “categorize the emotion expression” by selecting a single emotion word best fitting with the face stimulus (1 = anger, 2 = disgust, 3 = fear, 4 = happy, 5 = sad, 6 = surprise, 7 = unclear/unsure). Reponses indicating an accurate categorization were coded as ‘1’, and responses indicating an inaccurate categorization or unclear/unsure were coded as ‘0’. After participants made a categorization response, they were then asked “How intense was the emotion expression?”, with response options ranging from 1 (*not at all*) to 7 (*very much*). Participants viewed, categorized, and rated the face for each target identity (4), emotion expression (6), and color version (2; color-variant vs. color-invariant), for a total of 48 trials. The order of trials was randomized.

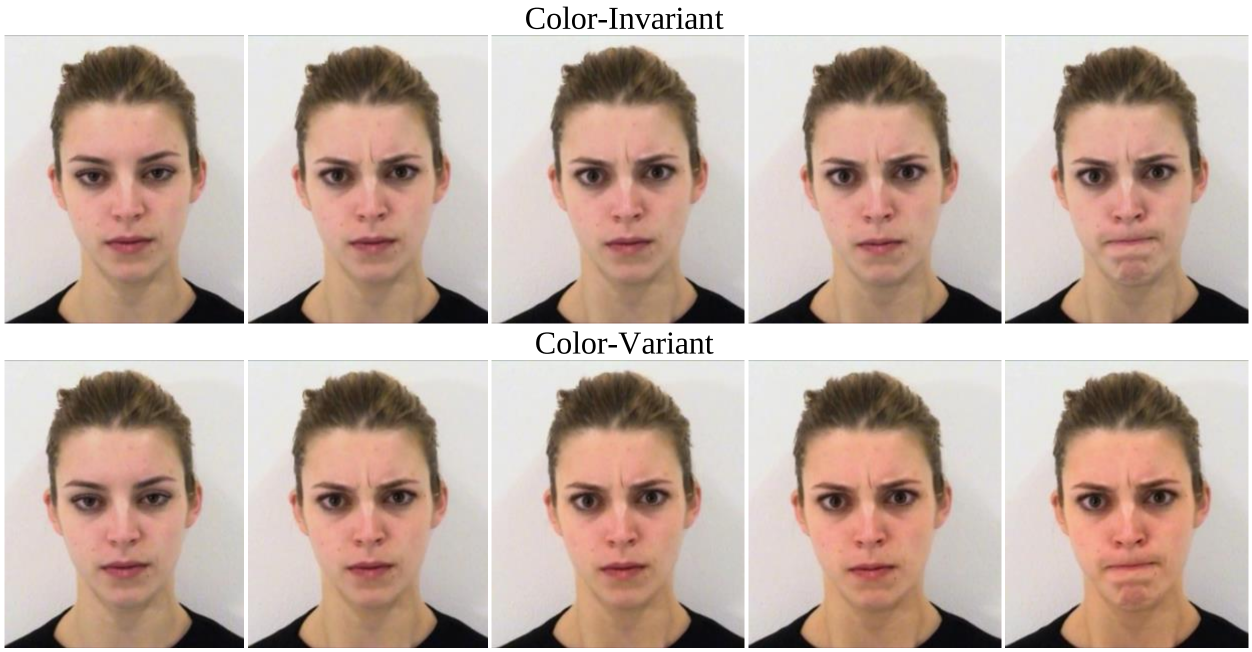

Figure 1. Example of a video sequence from Experiment 1. Faces expressed an emotion from neutral (left) to maximally expressive (right) across 1 second. Color-invariant stimuli did not change facial color across the sequence, while color-variant stimuli either increased (shown) or decreased in facial redness and yellowness linearly across the sequence.

Results and Discussion

Due to the nested structure of the data, multilevel modeling was chosen for statistical analysis (HLM: Bryk & Raudenbush, 1992). We built a two-level model with perceived emotion intensity ratings modeled as the outcome variable at Level 1, along with color condition (dummy coded; 0 = invariant, 1 = variant), emotion type (dummy coded; 0 = paling, 1 = blushing), and their interaction as predictors. Participants were modeled at Level 2 with no predictors. The intercept at Level 2 was treated as a random effect. To compute effect sizes (represented by β), we ran identical models with standardized color intensity ratings as the outcome variable. This indicates perceived intensity differences in terms of standard deviations across color conditions and emotion types.

The intercept (i.e., intensity ratings for color invariant, paling emotions) was 4.52. There was a main effect of color condition, $b = .28$, $SE = .039$, $\beta = .18$, $t(6236) = 7.11$, $p < 0.001$, indicating that color variant trials were perceived as stronger in intensity. There was also a main effect of emotion type, $b = .11$, $SE = .049$, $\beta = .07$, $t(6236) = 2.33$, $p = .020$, such that blushing emotions were perceived as stronger in intensity than paling emotions. The interaction between color condition and emotion type was significant, $b = -.16$, $SE = .052$, $t(6236) = -3.01$, $p = .003$. Simple effects analyses indicated that color variant trials increased perceived intensity for both emotion types, but the effect was stronger for paling emotions ($b = .28$, $p < .001$, $\beta = .18$) relative to blushing emotions ($b = .12$, $p = .001$, $\beta = .08$).

Next, we created the same model substituting emotion categorization accuracy as the Level 1 outcome variable with a nonlinear Bernoulli distribution (coefficients reflect log-odds). Participants had a mean accuracy of 87.29% across all trials. Color variant trials significantly increased accuracy, $b = .21$, $SE = .070$, $t = 3.06$, $p = .003$, $OR = 1.24$. Blushing emotion trials had higher accuracy than paling emotion trials, $b = 1.58$, $SE = .161$, $t = 9.82$, $p < .001$, $OR = 4.84$. The interaction did not reach significance ($b = -.24$, $p = .15$), indicating that color information increased accuracy similarly for blushing and paling emotions (see Figure 2 for a summary of the results).

We conducted ancillary analyses to examine whether target sex and/or participant sex moderated any of these results. For intensity ratings, only a main effect of target sex emerged, such that emotions for male targets were perceived as less intense that female targets ($b = -.80$, $SE = .07$, $p < .001$). For emotion accuracy, only a main effect of participant sex emerged, such that men were less accurate than women ($b = -.56$, $SE = .20$, $p = .006$). No other main effects or interactions were observed for either outcome variable.

To further examine how dynamic color changes corresponded to perceived emotion intensity and accuracy across individual emotion categories, we conducted repeated measures ANOVAs on emotion intensity and emotion accuracy with color condition (2 levels) and emotion category (6 levels) as independent variables. Intensity ratings were averaged across target identities, as were accuracy ratings (thus indicating the proportion of accurate categorizations across trials).

For intensity ratings, the two-way interaction between color condition and emotion type was significant, $F(5, 655) = 3.19$, $p = .008$, $\eta_p^2 = .024$, indicating that the effect of color variance on perceived intensity differed across emotion categories. Simple effects analyses revealed that color variant trials significantly increased perceived intensity of anger (*Mdifference* = .20, *SDdifference* = .66, $p = .001$, $d = .31$), disgust (*Mdifference* = .30, *SDdifference* = .71, $p < .001$, d =.43), fear (*Mdifference* = .21, *SDdifference* = .63, $p < .001$, d =.33), and sadness (*Mdifference* = .33, *SDdifference* = .73, $p < .001$, d =.45). The difference for surprise was marginally significant

(*Mdifference* = .10, *SDdifference* = .67, p = .083, d =.15). No difference was observed for happiness (*Mdifference* = .08, *SDdifference* = .61, p = .15, d = .13)

For accuracy in emotion recognition, main effects of color condition (F = 7.30, p = .008, eta = .05) and emotion type (F = 82.50, p < .001, η_p^2 = .39) emerged. The two-way interaction was marginally significant (F = 1.94, p = .086, η_p^2 = .02). Simple effects analyses indicated that sadness categorizations were more accurate for color variant trials (*Mdifference* = .05, *SDdifference* = .21, p = .015, d = .22). Fear was marginally more accurately categorized for color variant trials (*Mdifference* = .05, *SDdifference* = .27, p = .059, d = .17), and accuracy did not vary as a function of color changes for the other four emotions (all ps > .32).

These results were largely in accordance with our hypotheses. Changes in facial color along the redness and yellowness dimensions led participants to perceive the emotion expressions as more intense. The facial coloration changes also generally facilitated more accurate emotion categorizations, indicated by the significant main effects of coloration in both the HLM and ANOVA analyses. However, it is worth noting that when analyzing the emotion categories separately, we did not find additional evidence that accuracy was facilitated by coloration for each discrete category.

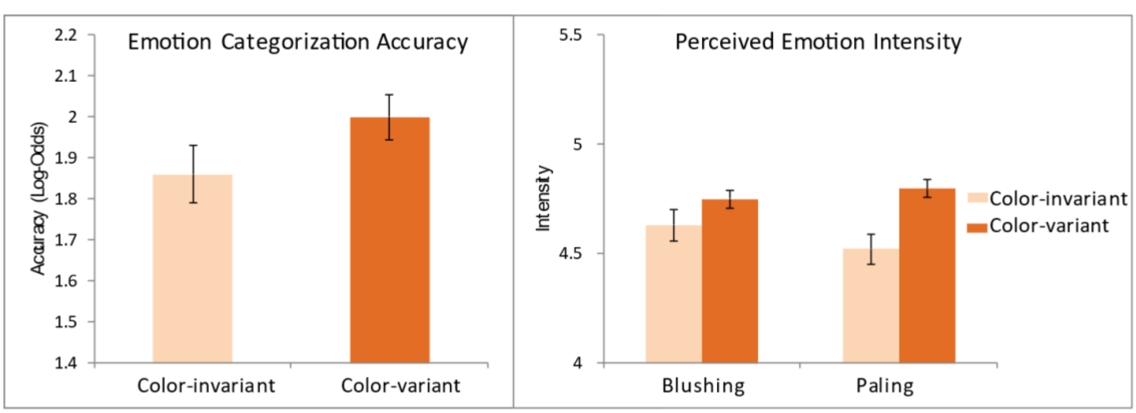

Figure 2. Emotion categorization accuracy (left) and perceived emotion intensity (right) in Experiment 1. Color-variant stimuli were categorized more accurately than color-invariant stimuli. Color-variant stimuli were perceived to be more intense than color-invariant stimuli for both blushing and paling emotions, although the effect was stronger for paling emotions. Error bars represent SEM.

Experiment 2

The results of Experiment 1 suggest that dynamic facial expressions changing in color (i.e., color-variant) facilitate emotion categorization accuracy and perceived intensity, relative to expressions that do not change facial color (i.e., color-invariant). In Experiment 2, we conducted a similar procedure, with the exception that the emotion expressions were static (i.e., still frames). We tested the same hypothesis that color-variant (vs. color-invariant) expressions of emotion would facilitate emotion categorization accuracy and perceived emotion intensity.

Method

Participants. One-hundred-nineteen (84 female; M_{age} = 20.17, SD_{age} = 1.39) undergraduate students participated in the experiment in exchange for course credit. No participants reported having a color vision deficiency.

Stimuli. The same 48 stimuli as in Experiment 1 were used. Instead of presenting the full videos, we showed only the final still frame of the sequence, representing the peak of the emotional display. The original, unmanipulated still frames were used as the color-invariant stimuli, and the final still frames comprising the maximum facial color change (+/- 5 units CIELAB a* and CIELAB b*) were used as the color-variant stimuli.

Procedure. Participants completed the procedure under the same display and viewing conditions as in the previous experiment. The procedure was identical to that of the previous experiment, with the exception that participants saw expressive still frames, which were presented for a duration of 1 second, for a total of 48 trials.

Results and Discussion

The same multilevel models as those from the previous experiment were used. For emotion intensity, the intercept (i.e., intensity ratings for color invariant, paling emotions) was 4.73. There was a main effect of color condition, $b = .31$, $SE = .046$, $\beta = .20$ $t(5708) = 6.77$, $p < 0.001$, indicating that color variant trials were perceived as stronger in intensity than color invariant trials. There was also a main effect of emotion type, $b = -.10$, $SE = .047$, $\beta = -.06$ $t(5708) = -2.15$, $p = .031$, such that blushing emotions were perceived as lower in intensity than paling emotions. The interaction between color condition and emotion type was significant, $b = -.16$, $SE = .054$, $t(5708) = -2.93$, $p = .004$. Simple effects analyses indicated that color variant trials increased perceived emotion intensity for both emotion types, but the effect was stronger for paling emotions ($b = .31$, $p < .001$, $\beta = .20$) than for blushing emotions ($b = .15$, $p < .001$, $\beta = .10$).

Participants had a mean accuracy of 82.81% across all trials. Color condition did not affect accuracy, $b = .11$, $SE = .069$, $t = 1.57$, $p = .12$, $OR = 1.11$. Blushing emotion trials had higher accuracy than paling emotion trials, $b = 1.11$, $SE = .135$, $t = 8.24$, $p < .001$, $OR = 3.04$. The interaction did not reach significance ($b = -.16$, $p = .13$). Figure 3 gives a summary of the results.

We conducted ancillary analyses to examine whether target sex and/or participant sex moderated any of these results. For perceived intensity, a four-way interaction between color, emotion type, target sex, and participant sex emerged, $b = .43$, $p = .049$. We investigated intensity ratings separately for male and female participants. For men, color variant trials increased perceived emotion intensity ($b = .30$, $p = .013$). Men also perceived emotions expressed by male targets as less intense than female targets ($b = -.82$, $p < .001$). No other main or interactive effects emerged. For women, the three-way interaction was significant (b = -.30, p = .007). For blushing emotions, only a main effect of target sex emerged (b = -.81, p < .001), such that women perceived men's emotion expressions as less intense than women's expressions. For paling emotions, the effect of color condition on perceived intensity varied across the sex of the target (b = .42, p < .001). Color increased perceived emotion intensity more for male targets (b = .54, p < .001) than for female targets (b = .12, p = .064).

For accuracy, a three-way interaction between color, emotion type, and target sex emerged. For trials representing blushing emotions, only a target sex main effect emerged, such that participants were less accurate for male targets (b = -.89, p < .001). For paling emotions, only a main effect of color emerged, such that color variant trials increased accuracy (b = .23, p = .014).

To further explore how facial color corresponded to perceived emotion intensity and accuracy across individual emotion categories, we conducted repeated measures ANOVAs on emotion intensity and emotion accuracy with color condition (2 levels) and emotion category (6 levels) as independent variables. Intensity ratings were averaged across target identities, as were accuracy ratings (thus indicating the proportion of accurate categorizations across trials). For intensity ratings, the two-way interaction between color condition and emotion type was significant, $F(5, 600) = 3.21$, p = .007, $\eta_p^2 = .026$, indicating that the effect of color on perceived intensity differed across emotion categories. Simple effects analyses revealed that color variant trials significantly increased perceived intensity for anger (*Mdifference* = .25, *SDdifference* = .79, p = .001, d = .32), disgust (*Mdifference* = .23, *SDdifference* = .78, p = .002, d =.29), fear (*Mdifference* = .35, *SDdifference* = .87, p < .001, d =.40), happiness (*Mdifference* = .12, *SDdifference* = .59, p = .025, d = .21), and sadness (*Mdifference* = .35, *SDdifference* = .74, p <

.001, *d* =.48). No difference was observed for surprise (*Mdifference* = .07, *SDdifference* = .69, *p* = .29, *d* = .10).

For accuracy in emotion recognition, the two-way interaction between color condition and emotion type was significant, $F(5, 600) = 2.24$, $p = .049$, $\eta_p^2 = .018$, indicating that the effect of color variance on accuracy differed across emotion categories. Simple effects analyses indicated that categorization accuracy for color variant trials was higher for happiness (*Mdifference* = .12, *SDdifference* = .59, $p < .001$, $d = .33$). Accuracy did not vary as a function of color changes for the other five emotions (all *p*s > .12).

We found partial support for our hypotheses. Consistent with the previous experiment, changes in facial coloration increased perceived intensity ratings for blushing and paling emotion expressions. However, we did not find evidence of an advantage in categorization accuracy as a function of color change.

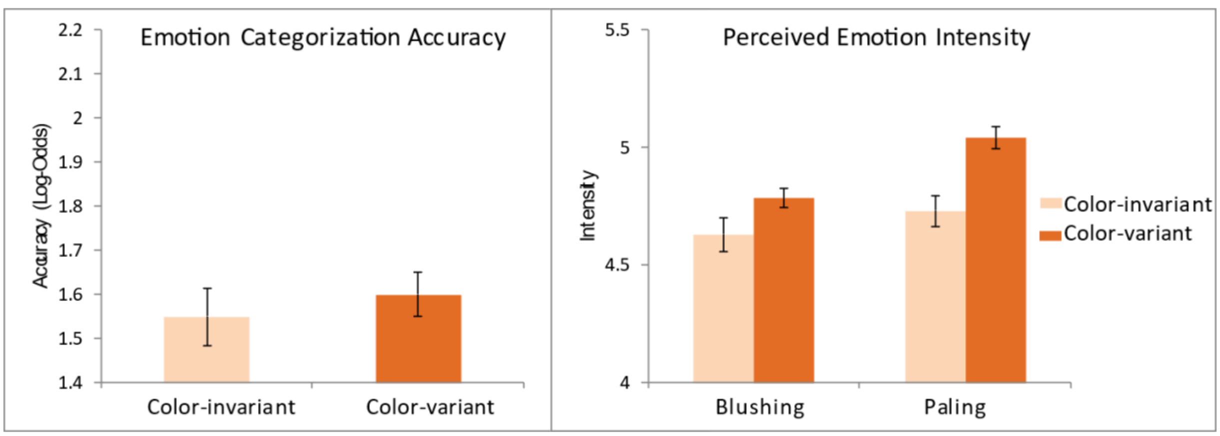

Figure 3. Emotion categorization accuracy (left) and perceived emotion intensity (right) in Experiment 2. Color condition did not significantly influence emotion categorization accuracy for static stimuli. Color-variant stimuli were perceived to be more intense than color-invariant stimuli for both blushing and paling emotions, although the effect was stronger for paling emotions. Error bars represent SEM.

Experiment 3

The results of Experiment 2 demonstrated that static color-variant expressions facilitated perceived emotion intensity relative to color-invariant ones (consistent with Exp. 1). However, there was no evidence that color-variant faces influenced emotion categorization accuracy, relative to color-invariant ones, for static emotion expressions (inconsistent with Exp. 1). This might be due to the fact that static expressions lack information regarding directional change (e.g., changing facial color from baseline), which has been shown to be a facilitating mechanism of dynamic expressions (Krumhuber, Kappas, & Manstead, 2013). Next, we were interested in one potential mechanism underlying the influence of facial color on emotion perception: memory. In Experiment 3, we tested whether memory for emotion expressive faces was biased with regard to facial color. We presented participants with dynamic expressions of emotion and subsequently had them recall the color of the faces. We expected that memory for facial coloration would be biased consistent with the emotion category prototype. Specifically, we expected that blushing emotion expressions would be misremembered as being more red/yellow than the originally displayed stimuli, while memory for paling emotion expressions would be biased toward decreased redness/yellowness.

Method

Participants. One-hundred-thirty-eight (113 female; M_{age} = 20.01, SD_{age} = 0.98) undergraduate students participated in exchange for course credit. Seven participants reported having a color vision deficiency and were removed from subsequent analyses.

Stimuli. We used the same (color-invariant) videos as in Experiment 1. In order to test recognition memory, facial stimuli were manipulated to create stimulus sequences with different color variance. For this, each target face was manipulated to change in color using MATLAB. Each image (regardless of emotion category) was manipulated to change in facial color by +/- 8 units of redness (CIELAB a*) and yellowness (CIELAB b*) from the original image in 9 steps. This resulted in 9 total images for each face encompassing the full range of facial color difference (Image 1 = original image -8 a*/b*, Image 2 = original -6 a*/b*, Image 3 = original -4 a*/b*, Image 4 = original -2 a*/b*, Image 5 = original image, Image 6 = original +2 a*/b*, Image 7 = original +4 a*/b*, Image 8 = original +6 a*/b*, Image 9 = original +8 a*/b*). Figure 4 shows an example of the set of response options used in the current experiment.

Procedure. Participants completed the experiment under the same display and viewing conditions as previously described. Eprime was used for stimulus presentation. The current experiment had two phases: a viewing phase and a recall phase. In the viewing phase, participants were instructed that they would be viewing a series of videos of people expressing various emotions, and that they would be asked to categorize each emotion. For each trial, a fixation cross was presented on the screen for 1s, followed by the onset of an emotion expression video, which played for 1s. Only color-invariant videos were presented to participants to avoid introducing any additional bias or attention regarding color-emotion associations in this phase. The video automatically disappeared after offset, and participants were asked to “categorize the emotion expression” as in Experiment 1. However, these responses were not coded or analyzed in the current experiment as they were meant to serve as a viewing task only. Participants viewed a video for each target identity (4) and emotion expression (6), for a total of 24 viewing trials.

After a 3-minute break (participants were simply asked to wait during the break), participants began the recall phase. For each trial in this phase, participants were asked “Which face do you remember seeing?” and were presented with the 9 image response options that comprised a range of facial color differences. Each of the response options for a given trial was identical in target identity and emotion expression, but varied in facial color. The responses were coded from 1 (maximally decreased facial redness and yellowness) to 9 (maximally increased facial redness and yellowness). All response options were presented simultaneously on one screen, selection time was unlimited, only one image could be selected, and no feedback was provided (for a similar procedure, see Wang et al., 2018). Participants made a selection for each target identity (4) and emotion expression (6), for a total of 24 recall trials. The trial order and image response option order were randomized.

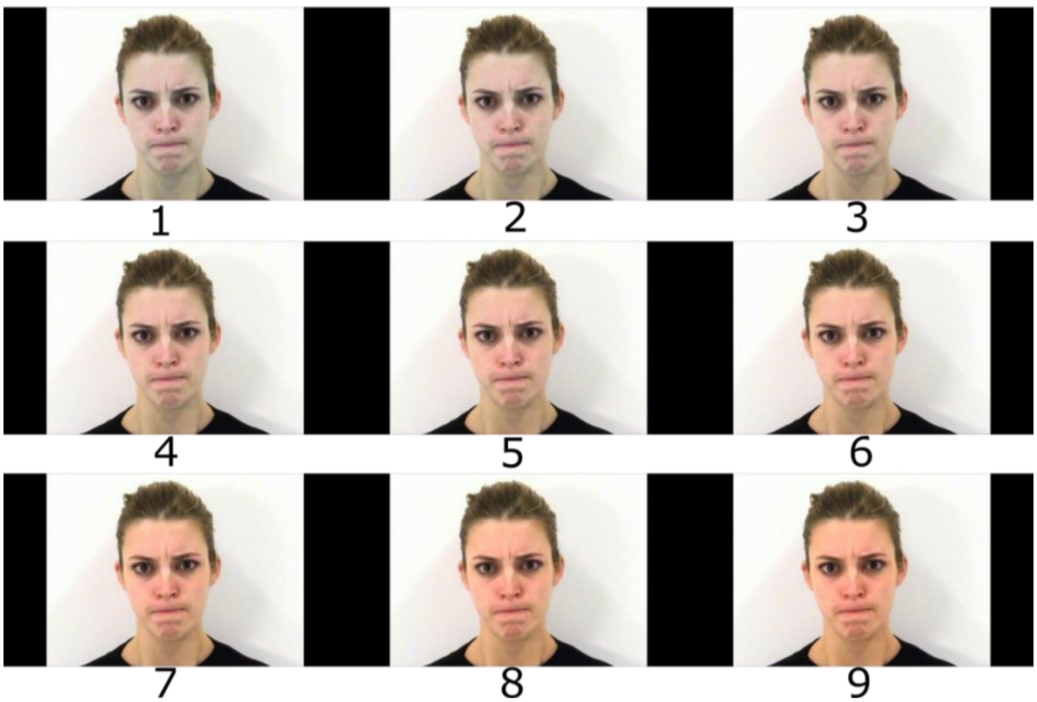

Figure 4. Example of response options in Experiment 3. Responses ranged from 1 (maximally decreased facial redness and yellowness) to 9 (maximally increased facial redness and yellowness). Image response options as shown in this figure are ordered, but image order was randomized in the experiment.

Results and Discussion

We created a two-level model in HLM. Color selections were recoded to a scale from -4 to 4, such that zero represented the original image, positive numbers indicate increased redness/yellowness, and negative numbers indicate decreased redness/yellowness. These recoded color selections were modeled as the Level 1 outcome variable. Emotion type (dummy coded; 0

= paling, 1 = blushing) was modeled as a Level 1 predictor. Participants were modeled at Level 2 with no predictors. The intercept at Level 2 was treated as a random effect.

The intercept was significantly different from zero (i.e., the original baseline stimuli), b = 1.76, SE = .08, t(129) = 21.84, p < .001, indicating that participants misremembered paling emotions as being redder/yellower than the stimuli that were actually displayed. Recoding the emotion type, such that 0 = blushing also yielded a statistically significant intercept, b = 1.91, SE = .07, t(129) = 26.45, p < .001, indicating that blushing emotions were also misremembered as being redder/yellower than the original stimuli. Importantly, the effect of emotion type was significant, b = .15, SE = .056, t(3118) = 2.62, p = .009, indicating that participants misremembered blushing emotions as being redder/yellower than paling emotions (see Figure 5). Ancillary analyses with participant sex and target sex included in the model failed to reveal any main or interactive effects for either variable.

In a subsequent set of analyses, we examined color memory separately for each of the six emotion categories. We conducted a series of one-sample t-tests (against a test value of zero). Significant differences emerged for each discrete emotion category (*Mdifferences* ranged from 1.57 – 1.99; *d*s ranged from 1.31 – 1.79; all *p*s < .001.

We found partial support for our hypotheses. Blushing emotions were indeed misremembered as being redder/yellower than both the original stimuli, and the paling emotions, which is consistent with their general facial color-emotion associations. However, we expected that paling emotion expressions would be misremembered as being *less* red/yellow than the originally displayed stimuli; We observed the opposite pattern.

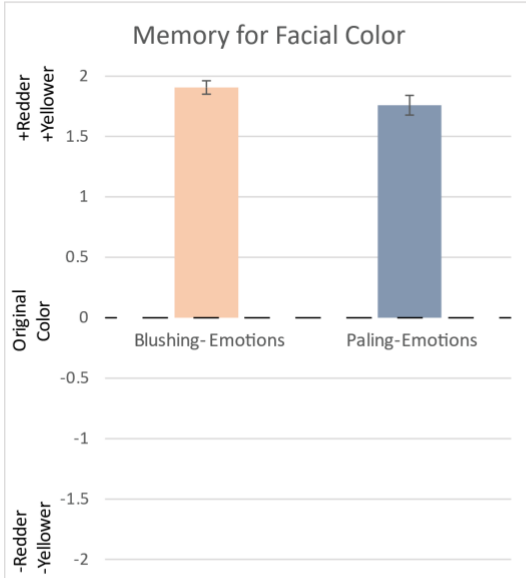

Figure 5. Memory for facial color in Experiment 3. Expressions of blushing emotions were misremembered as redder and yellower than those for paling emotions, but both were misremembered with increased coloration relative to the original stimuli. Error bars represent SEM.

Experiment 4

Experiment 3 revealed that memory for dynamic emotive faces was biased in facial coloration. Specifically, expressions of blushing emotions were misremembered as redder and yellower, relative to the original stimuli, and relative to paling emotions. This pattern of memory bias is consistent with generic face color-emotion associations found in previous research (Thorstenson et al., 2017). However, expressions of paling emotions were misremembered as redder and yellower than the original stimuli, which was inconsistent with our hypotheses. In Experiment 4, we conducted a similar procedure, with the exception that the faces initially presented (and asked to recall later) were static displays of emotion expressions. We tested the same hypothesis as in the previous experiment, such that memory for facial coloration would be biased in line with general facial color-emotion associations.

Method

Participants. One-hundred-forty (97 female; M_{age} = 20.06, SD_{age} = 1.29) undergraduate students participated in the experiment in exchange for course credit. One participant reported having a color vision deficiency and was removed from subsequent analyses.

Stimuli. The stimuli were the same as in Experiment 3, with the exception that only the final still frame of the video sequence was used, representing the peak of the emotional display.

Procedure. Participants completed the experiment under the same display and viewing conditions as previously described. The procedure was identical to that of Experiment 3, with the exception that the videos in the viewing phase were expressive still frames, which were presented for 1 second before offset. The recall phase was identical to that of the previous study.

Results and Discussion

We analyzed the data using the same multilevel model described in the previous experiment. The intercept was significantly different from zero, $b = 1.01$, $SE = .09$, $t(138) = 10.86$, $p < .001$, indicating that participants misremembered paling emotions as being redder/yellower than the stimuli that were actually displayed. Recoding the emotion type, such that 0 = blushing also yielded a statistically significant intercept, $b = 1.20$, $SE = .09$, $t(138) = 13.50$, $p < .001$, indicating that blushing emotions were also misremembered as being redder/yellower than the original stimuli. Importantly, the effect of emotion type was also significant, $b = .19$, $SE = .066$, $t(3334) = 2.89$, $p = .004$, indicating that participants misremembered blushing emotions as being redder/yellower than paling emotions (see Figure 6). Ancillary analyses with participant sex and target sex included in the model failed to reveal any main or interactive effects for either variable.

In a subsequent set of analyses, we examined color memory separately for each of the six emotion categories. We conducted a series of one-sample t-tests (against a test value of zero).

Significant differences emerged for each of the discrete emotion categories (*Mdifferences* ranged from .95 – 1.52; *d*s ranged from .75 – 1.22; all *p*s < .001).

These results are consistent with those from Experiment 3. Expressions for blushing emotions were misremembered as being redder/yellower than the original stimuli and those of the paling emotions, which is consistent with these facial color-emotion associations. Again, and counter to predictions, paling emotion expressions were also misremembered as being redder/yellower than the original stimuli.

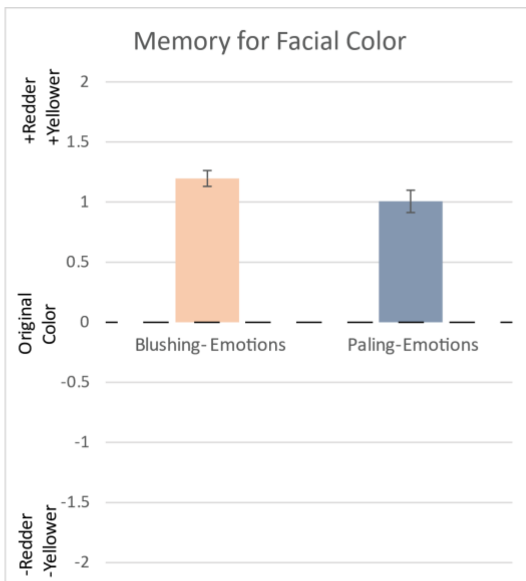

Figure 6. Memory for facial color in Experiment 4. Expressions of blushing emotions were misremembered as redder and yellower than those for paling emotions, but both were misremembered with increased coloration relative to the original stimuli. Error bars represent SEM.

General Discussion

This research examined whether changes in facial coloration influenced the perception of, and memory for, emotion expressions. The results provide evidence that facial coloration facilitated emotion categorization in dynamic (Exp.1) but not static displays (Exp.2). In both studies, facial coloration facilitated perceived emotion intensity. Furthermore, memory for emotion expressions was biased by facial coloration, in the sense that participants misremembered the facial coloration of dynamic (Exp. 3) and static (Exp. 4) expressions. Specifically, expressions for blushing emotions were recollected as being redder and yellower than both the original stimuli and the expressions for paling ones. Altogether, the current work suggests that facial color can facilitate emotion recognition accuracy (for dynamic expressions) and perceived emotion intensity, and that this influence may be grounded in cognitive processes involving memory.

The finding that facial coloration facilitated emotion recognition in dynamic but not static displays might reflect the fundamentally dynamic nature of facial coloration in emotion perception. During the course of display, facial color changes transiently over time (Cooper & Gerlach, 2013), and the perception of facial coloration relies on the directional change in color (Changizi et al., 2006). In other words, people need to have comparative knowledge regarding the initial baseline facial color in order to detect and interpret any subsequent changes in facial coloration. In Experiment 1, participants viewed dynamically expressive stimuli, starting from a neutral expression and then dynamically unfolding in emotion and color. Such protocol afforded participants the critical comparative information regarding the change of facial color from baseline. Conversely, in Experiment 2 participants only viewed the maximally expressive images (encompassing only the maximum color information), which likely either precluded detection of any color differences, dampened inferences regarding the contribution of color on emotion, or both. Future research might be aimed at testing the stages (i.e., lower-level visual detection or higher-level working knowledge) at which dynamic versus static facial color information facilitates versus impedes emotion perception. However, in both experiments, facial coloration facilitated ratings of emotion intensity, indicating that participants still used the facial coloration information when making emotion inferences from static stimuli.

It is also worth noting that while we found supportive evidence that coloration facilitated recognition accuracy for dynamic stimuli (as indicated by significant main effects of coloration in both HLM and ANOVA models), we did not find additional evidence that accuracy was increased for each discrete emotion when analyzing simple effects individually. This could possibly stem from reduced statistical power invoked by the simple effects analyses, possible ceiling effects (mean accuracy was greater than 80%), a true reflection that coloration does not impact accuracy for each emotion category, or combinations of these. In any case, we thus view the findings taken together as supportive, yet limited, regarding the facilitating influence of facial coloration on emotion recognition accuracy for dynamic (but not static) stimuli.

The results from Experiments 3 and 4 demonstrated that memory for emotion expressions was biased by facial coloration. Face perception and memory have been shown to be malleable and subject to biases (Hugenberg & Sacco, 2008), such that faces are misremembered as looking more prototypical of their social category than they objectively are (Corneille et al., 2004; Huart, Corneille, & Becquart, 2005). Consistent with evidence showing that emotions are often represented as categorical prototypes (Shaver, Schwartz, Kirson, & O'Connor, 1987) which contain associative links with facial color (Thorstenson et al., 2018), expressions for blushing emotions were misremembered as redder and yellower than those for paling emotions. Moreover, and counter to hypotheses, both emotion types were misremembered with increased facial redness and yellowness relative to the original stimuli. A possible explanation for this finding is that preferred (i.e., evaluated as more likeable or attractive) facial colors in images are more chromatic (in this case, redder and yellower) than real facial colors (Zeng & Luo, 2013). Given that preferred images facilitate visual attention capture (Shimojo, Simion, Shimojo, & Scheier, 2003), participants may have demonstrated a bias to attend more to, and select, slightly redder and yellower faces because they were preferred to the original images. Furthermore, skin coloration is related to other (non-emotional) social evaluations. For example, slightly redder and/or yellower skin coloration tends to facilitate perceptions of health, attractiveness, and dominance when evaluating faces (e.g., Henderson et al., 2017; Lefevre et al., 2013; Pazda et al., 2016; Re et al., 2011; Rowland & Burriss, 2017; Stephen et al., 2009; Stephen et al., 2012; Thorstenson et al., 2016). It is thus possible that participants also drew upon these or other conceptual face-color associations outside the domain of emotion to make their selections. Finally, it has been demonstrated that memory impacts perception of color for faces in unique ways relative to other object colors (Hasantash et al., 2019), so it could be the case that our intial hypotheses do not fully account for the distinctive nature of perceiving color on faces. Additional work is warranted to better understand the current observerations.

In the current work, we manipulated facial color holistically (i.e., across the entire face), linearly (i.e., changing at a constant rate over time), and divergently (either increasing or decreasing in redness and yellowness according to emotion type). We also collapsed the emotions into two types, labeled “blushing” and “paling”, to summarize the expressions that increased versus decreased in facial coloration, respectively. This is not meant to imply that facial color necessarily unfolds over time precisely in that manner in real life, or that emotions within these labels are conceptually equivalent or meaningfully comparable beyond the current color manipulations. For instance, recent work has shown that regional patterns (as opposed to holistic patterns) of facial coloration uniquely differentiate between at least 18 discrete emotion expressions (Benitez-Quiroz et al., 2018). Further, facial color-emotion associations between discrete emotion categories are not identical in magnitude or chromatic axis (Thorstenson et al., 2018), and some emotions (e.g., fear) can be perceived with either increased *or* decreased facial coloration (Thorstenson et al., 2021). Finally, facial coloration likely unfolds at disparate rates and magnitudes between (and likely within) discrete emotion expressions. We chose to hold these factors constant in this initial work to avoid potential confounds that might obfuscate inferences. Future research would be worthwhile to better explicate how facial color is naturally expressed over time across distinct emotion expressions.

A limitation of the current work was the selection of solely Caucasian faces as target stimuli. Given the narrow set of stimuli, it is unknown how well the current results generalize across other target ethnicities (see also Simons, Shoda, & Lindsay, 2017). This is a significant question given that the influence of subtle facial coloration (i.e., chromatic) changes may reasonably be affected by variable baselines of skin color. Some research has suggested that subtle facial coloration changes are expressed during emotions, and influence perceptions of emotions, comparably across a range of actor and target ethnicities (Benitez-Quiroz et al., 2018; Changizi et al., 2006). Nevertheless, additional work explicitly addressing how facial colorations change with emotion as a function of ethnicity is needed to determine the generalizability of the current work.

The present work suggests that holistic changes in facial color can be used to augment the expressive capability of social agents; a finding which has direct practical implications for developing artificial social agents such as social robots, avatars, and virtual environments (Chen et al., 2018; Küster, Krumhuber, & Kappas, 2014). Finally, the current research provides support for a social functional account of facial coloration in emotion communication, such that facial color affords an advantage in detecting and interpreting the emotional state of others. In a similar vein, recent research has demonstrated that diverging facial color information can facilitate the disambiguation of emotion expressions (Thorstenson, Pazda, Young, & Elliot, 2019), and serve as an ‘honest’ signal of emotion (Thorstenson, Pazda, & Lichtenfeld, 2019). The current work also supports the notion that trichromatic color vision plays an important role in social communication via the perception of skin coloration (see also Changizi, Zhang, & Shimojo, 2006; Hasantash et al., 2019; Hiramatsu et al., 2017; Thorstenson, 2018; Thorstenson et al., 2020). In sum, the current work provides evidence that facial coloration information is used in multiple aspects of emotion processing, highlighting the role of facial coloration in how people are perceived and remembered.

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