Research article

Effects of color–emotion association on facial expression judgments

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A B S T R A C T

Color and emotion are metaphorically associated in the human mind. This color–emotion association affects perceptual judgment. For example, stimuli representing colors can affect judgment of facial expressions. The present study examined whether colors associated with happiness (e.g., yellow) and sadness (e.g., blue and gray) facilitate judgments of the associated emotions in facial expressions. We also examined whether temporal proximity between color and facial stimuli interacts with any of these effects. Participants were presented with pictures of a happy or sad face against a yellow-, blue-, or gray-colored background and asked to judge whether the face represented happiness or sadness as quickly as possible. The face stimulus was presented simultaneously (Experiment 1) or preceded for one second by the colored background (Experiment 2). The analysis of response time showed that yellow facilitated happiness judgment, while neither blue nor gray facilitated sadness judgment. Moreover, the effect was found only when the face and color stimuli were presented simultaneously. The results imply that the association of sadness with blue and gray is weak and, consequently, does not affect emotional judgment. Our results also suggest that temporal proximity is critical for the effect of the color–emotion association (e.g., yellow–happiness) on emotional judgment.

1. Introduction

Human beings often express emotions by linguistically linking them with colors in daily conversations. For instance, one can express sadness using the word "blue" such as "*feeling blue*" in English and Japanese. However, humans also associate emotions with the visual perception of colors (Jonauskaite et al., 2020b). For example, in text chat, one might use an emoticon of a red-colored face in a sentence to convey anger. Indeed, because one's anger coincides with increased blood flow and a flushed face, people might have learned from seeing red in an angry face (Benitez-Quiroz et al., 2018). These linguistic and perceptual associations, so-called color–emotion associations (Boyatzis and Varghese, 1994; Elliot and Maier, 2012; Hemphill, 1996; Palmer and Schloss, 2010), are common in humans across cultural groups (Jonauskaite et al., 2020a).

The conceptual metaphor theory (Lakoff and Johnson, 1980) may account for the color–emotion association. According to this theory, to understand abstract concepts related to thought and action, humans apply the structures of other, concrete concepts to the targeted abstract concepts. Therefore, concepts related to emotions, which do not have clear contours, are understood by using the concepts of colors, which are

clear perceptual experiences, as a scaffold (Lakoff and Johnson, 1999; Williams et al., 2009). In other words, the metaphorical structures of concepts such as "sadness is blue" and "anger is red" facilitate understanding concepts related to emotions.

Due to such associations, the perception of colors may explicitly and/or implicitly remind people of corresponding emotions and even bias their judgments of emotional stimuli. For example, Jonauskaite et al. (2020b) presented words and patches of several colors to participants and asked them to choose emotions that are associated with the colors. Their results showed that participants tended to associate anger and love with red, sadness with gray, and joy with yellow, regardless of whether the colors were presented verbally or visually. Thus, it was suggested that colors and emotions are associated in human cognition. In addition, Fetterman et al. (2012) presented anger- and sadness-related words written in blue or red and asked participants to categorize them. Their results revealed that anger-related words were categorized faster when colored red than when colored blue, suggesting that perception of red, which is associated with the concept of anger, enhances linguistic processing related to anger.

In terms of social cognition, it is important for humans to understand others' emotional states. Facial expressions function as one of the most

effective cues when people recognize others' emotions (Collignon et al., 2008; Ikeda, 2020; Massaro and Egan, 1996; Van den Stock et al., 2007). Humans also utilize other resources, including emotional contexts (Barratt et al., 2016). Similarly, colors associated with emotions also affect the recognition and judgment of emotions based on facial expressions. In a study conducted by Young et al. (2013), participants were asked to categorize presented pictures of faces displaying happiness and anger against backgrounds colored red, green, or gray as one of two emotions. In another experiment (Young et al., 2013), participants categorized angry and fearful faces against red, blue, or gray backgrounds. The results showed that judgment of angry faces was fastest against a red background in both experiments, suggesting that red facilitates recognizing angry faces due to a red–anger association. Moreover, in Ikeda (2020), participants categorized images of faces and emoticons representing happiness and anger presented against a red or green background (Experiment 1) and those representing happiness and sadness against a yellow or blue background (Experiment 2). As a result, angry images against a red background and happy images against a green and yellow background were correctly categorized faster than when the respective faces were presented against backgrounds of the other colors. These results suggest that metaphorical associations of anger and happiness with certain colors may be robust, and such associations are able to facilitate judgments of the associated emotions, including via facial expressions.

Although previous studies have suggested various color–emotion associations, some associations have been controversial, particularly the association between blue and sadness. For example, the perceived intensity of sadness in facial stimuli displaying ambiguous emotion was higher when the stimuli were colored in blue (Kato and Yamashita, 2016). Geometric patterns (e.g., circles, squares) drawn in blue tend to increase the sadness rating (Hevner, 1935). These findings suggest a blue–sadness association. However, this association is not ubiquitous. Given color-in-context theory (Elliot and Maier, 2012), color conveys different meanings depending on context; thus blue is not consistently associated with sadness. Indeed, according to ecological valence theory (Palmer and Schloss, 2010), blue is a preferred color since it is associated with environmental objects (e.g., clear sky and clean water) which people like (Palmer and Schloss, 2010; Yokosawa et al., 2016). Previous studies have also suggested blue is associated with positive emotions in some countries (Adams and Osgood, 1973; Jonauskaite et al., 2020b; Kaya and Epps, 2004; Valdez and Mehrabian, 1994; Wexner, 1954). In addition, a recent study has suggested that gray is more strongly associated with sadness than blue (Jonauskaite et al., 2020b). Therefore, it is unclear what colors are associated with sadness in human cognition.

In the present study, we followed Experiment 2 from Ikeda (2020) and employed a task in which participants judged whether a facial stimulus expressed happiness or sadness. To examine the effects of color associated with happiness and sadness on emotional judgments, we presented yellow and blue as the background of facial stimuli, colors that have been suggested to be associated with happiness and sadness, respectively (e.g., Ikeda, 2020). We also included a gray background, which has been suggested to be strongly associated with sadness (Jonauskaite et al., 2020b). Based on the results of previous studies (Ikeda, 2020; Jonauskaite et al., 2020b), we expected yellow to enhance happiness judgments; in other words, the number of error response would be smallest and the response time would be fastest for judgments of happy facial expressions against a yellow background. We also examined whether blue and gray facilitate sadness judgment and which color, if any, affects the judgment more strongly. We hypothesized that if sadness is more closely associated with gray than with blue, then the judgment of sadness would be faster and more accurate with the gray than with the blue or yellow background.

Previous studies have investigated effects of colored background on facial expression judgments using different presentation procedures. One is color priming presentation (Young et al., 2013). They presented red backgrounds before facial expression stimuli to prime participants for a threatening context, demonstrating that the judgment of anger was

facilitated. The other is simultaneous (Stroop-like) presentation of color and facial stimuli. Studies using simultaneous presentation have shown that colored backgrounds affect judgment of emotions in happy and sad faces (Gil and Le Bigot, 2014; Ikeda, 2020) and in emotionally ambiguous faces (Gil and Le Bigot, 2015). Results of studies using these procedures showed significant effects of color on facial expression judgments regardless of temporal proximity of color and facial stimuli. However, the differences in the color–emotion association effect between simultaneous and serial presentations (i.e., Stroop vs. priming) have not been examined. Thus, in the present study, we compared a Stroop-like task (Experiment 1) and a priming task (Experiment 2) by using the same colors and emotional facial stimuli and examined the difference in the color–emotion association effect on emotional judgments.

2. Experiment 1

2.1. Materials and methods

2.1.1. Participants

Twenty-one Japanese female university students participated. One participant, whose individual mean response time exceeded the range of mean response time across participants ±2 *SD*, was excluded from data analysis. Mean age of the remaining 20 participants was 20.00 years (*SD* = 1.84, range 18–24). All participants reported that Japanese was their only native language and that they had normal or corrected-to-normal visual acuity and normal color vision.

Although our sample size was not determined based on *a priori* power analysis, *post hoc* power analysis using G*Power 3.1.9.6 (Faul et al., 2007) revealed statistical power of .776, .798, and .969 for non-significant simple main effects of Emotion on response time in the blue- and gray-background conditions and simple main effect of Color on response time for sadness judgment, respectively (see the Results section). We conclude that our sample size was adequate for the purpose of the present study.

Each participant provided written informed consent before the experiment. The present study was conducted in accordance with the Declaration with Helsinki and approved by the ethics committee of Ochanomizu University (approval number: 2020-98).

2.1.2. Stimuli and apparatus

As facial stimuli, we used images of the faces of eight Japanese adults (four males and four females) displaying happiness (M01-SO-1, M06-SO-1, M09-SO-2, M10-SO-4, F03-SO-2, F10-SO-2, F13-SO-2, F16-SO-2) and sadness (M01-SD-1, M06-SD-2, M09-SD-1, M10-SD-3, F03-SD-1, F10-SD-3, F13-SD-2, F16-SD-1) from the ATR Facial Expression Image Database (ATR-Promotions, 2006). The emotional intensity of facial stimuli were evaluated using a seven-point Likert scale (1–7) in the experiment conducted by ATR-Promotions (2006), which reported that the mean score of happiness (range of 6.30–6.85) was higher than that of sadness (1.07–1.33) for each happy facial stimulus and mean score of sadness (5.22–6.33) was higher than that of happiness (1.11–1.22) for each sad facial stimulus. The images were converted to gray scale, their backgrounds were cropped, and they were subtended at approximately 9 × 12° visual angle. Each facial stimulus was presented in the center of the background, which was colored yellow (RGB = 255/255/0), blue (RGB = 0/0/255), or gray (RGB = 102/102/102). In practice trials, images of two other Japanese males expressing happiness (M02-SO-1, M05-SO-3) and sadness (M02-SD-1, M05-SD-3) were presented on a black background (RGB = 0/0/0).

The instructions and stimuli were presented on a 24-inch liquid crystal display monitor (E2483HS, iiyama Corp.). Participants viewed the monitor from a distance of 53 cm with a chin rest and responded using a QWERTY keyboard with both index fingers. Stimulus presentation and response collection were controlled by PsychoPy 2020.1.3 (Peirce et al., 2019) running on a Windows 10 computer (Optiplex 7060SF, Dell Inc.).

2.1.3. Procedures

The experiment was conducted individually in a dark, quiet room. In each experimental trial, a white fixation cross was presented in the center of a black screen for one second and followed by the facial stimulus against the colored background, which was presented until the participants responded (Figure 1A). The participants were asked to ignore the background colors and judge whether the face expressed happiness or sadness as quickly and accurately as possible by pressing the X or slash key on the keyboard. Correspondence between the response key and the emotion was counterbalanced across participants. Participants completed two blocks, in which trials with eight each of the happy and sad stimuli against yellow, blue, and gray backgrounds were repeated twice in a randomized order (i.e., 96 trials per block). Participants were permitted to take a break between blocks. Prior to the main experiment, the participants completed eight practice trials.

2.2. Results

The number of error response and mean response time in each condition served as dependent variables to test the effects of the color–emotion association on performance of emotional judgment. Data analysis was performed with JASP 0.14.1 (JASP Team, 2020) and R 4.0.2 (R Core Team, 2020).

2.2.1. Number of error response

Generalized linear mixed modelling (GLMM) was performed for number of error responses with Poisson family distribution and square-root link function. Fixed effects were Emotion in facial expression (happiness, sadness) and Color of background (blue, yellow, gray). The random effect was participants. As a result, intercept was significant ($\chi^2(1) = 40.32$, $p < .001$); there were no significant effects of Emotion ($\chi^2(1) = 0.16$, $p = .686$) and Color ($\chi^2(2) = 2.18$, $p = .336$) or their interaction ($\chi^2(2) = 4.19$, $p = .123$). The accuracy of facial expression judgment was not affected by the facial expression, background colors, or their relations, possibly due to the floor effect from the easiness of binary judgment of happiness versus sadness. Indeed, median number of error responses per condition was one (out of 32 trials) with an interquartile range (IQR) of 0–2.

2.2.2. Response time

Trials with error responses and those with correct responses and a response time deviating from the individual mean ± 2 SD were excluded from the following analysis. As a result, a median of 5.99% of the trials (IQR of 5.21–7.68) were excluded.

The results regarding response time are summarized in Figure 2. The rmANOVA with Emotion and Color as within-participant factors revealed significant main effects of Emotion ($F(1, 19) = 5.03$, $p = .037$, $\eta_p^2 = .209$) and Color ($F(2, 38) = 4.11$, $p = .024$, $\eta_p^2 = .178$) and the interaction between Emotion and Color ($F(2, 38) = 6.45$, $p = .004$, $\eta_p^2 = .254$). The simple main effect of Emotion was significant when the background was colored yellow ($F(1, 19) = 10.80$, $p = .004$, $\eta_p^2 = .362$) but not when it was colored blue ($F(1, 19) = 0.30$, $p = .589$, $\eta_p^2 = .016$) or gray ($F(1, 19) =$
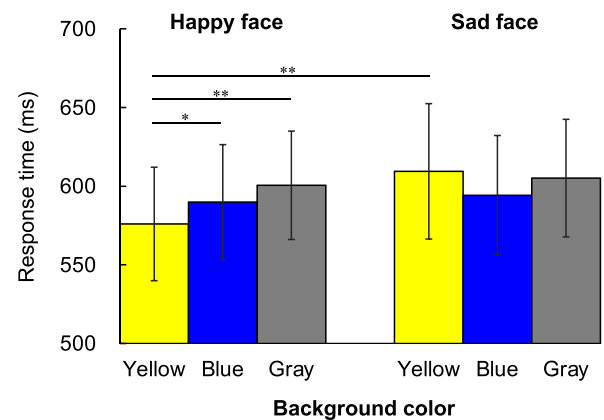
**Figure 2.** Mean response time in Experiment 1. Error bars represent 95% confidence interval. Asterisks indicate significant differences (*$p < .05$, **$p < .01$).

0.54, $p = .471$, $\eta_p^2 = .028$), suggesting a faster response for the happy face stimuli than for the sad face stimuli against a yellow background. Moreover, the simple main effect of Color was significant when the facial stimuli expressed happiness ($F(2, 38) = 9.95$, $p < .001$, $\eta_p^2 = .344$). *Post hoc* tests with the Holm-Bonferroni correction revealed that responses were faster when happy face stimuli appeared on yellow backgrounds versus blue ($t = 2.51$, $p = .033$, Cohen's $d = 0.56$) and gray backgrounds ($t = 4.45$, $p < .001$, $d = 1.00$). There was no significant difference between the response times for happy faces on the blue and gray backgrounds ($t = 1.94$, $p = .060$, $d = 0.43$). Conversely, simple main effect of Color was not significant when facial stimuli indicated sadness ($F(2, 38) = 2.52$, $p = .094$, $\eta_p^2 = .117$). These results suggest that judgment of happiness was influenced by simultaneously presented surrounding colors (especially yellow), while judgment of sadness was not.

2.3. Discussion

Experiment 1 examined whether color facilitates judgment of facial expressions, namely, happiness and sadness. The analysis of the number of error response found no significant effects of background colors or the emotions in the facial stimuli, perhaps due to the floor effect. The analysis of response time, on the other hand, showed that judgment of a happy face was faster than judgment of a sad face against a yellow background, consistent with the previous finding (Ikeda, 2020). However, contrary to our hypothesis, judgment of happy and sad faces was not affected by a blue or gray background. This suggests that yellow is associated with happiness and, consequently, promotes judgment of happy faces, whereas blue and gray have no or only a weak association with sadness (as well as with happiness) and do not affect sadness judgment.

To compare these results suggesting that simultaneous presentation induced the effect of yellow on happiness judgment, serial presentation
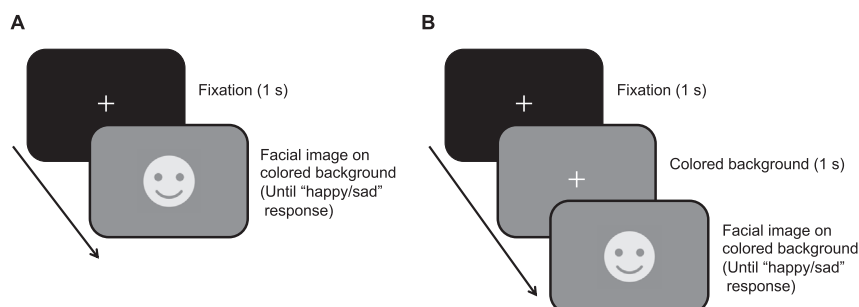
Figure 1. Schematic illustration of trials in (A) Experiment 1 and (B) Experiment 2.

of a colored background preceding facial stimuli was employed in Experiment 2.

3. Experiment 2

3.1. Materials and methods

3.1.1. Participants

A new set of 21 Japanese university students (three males) participated. Two participants (a male and a female) were excluded from analysis based on the same criteria as in Experiment 1. Mean age of the remaining 19 participants was 21.26 years ($SD = 1.97$, range 18–26). The *post hoc* power analysis revealed statistical power of .906 and .924 for non-significant main effects of Emotion and Color on response time, respectively.

3.1.2. Stimuli and apparatus

The stimuli and apparatus were identical to those in Experiment 1.

3.1.3. Procedures

The procedure was the same as in Experiment 1 except for the following: in each trial (Figure 1B), the colored background was presented for one second following the fixation cross. The facial stimulus was then superimposed against the colored background. The experiment consisted of four blocks of 48 trials each (i.e., 16 faces against three colored backgrounds). Participants were permitted to take breaks between blocks upon their request.
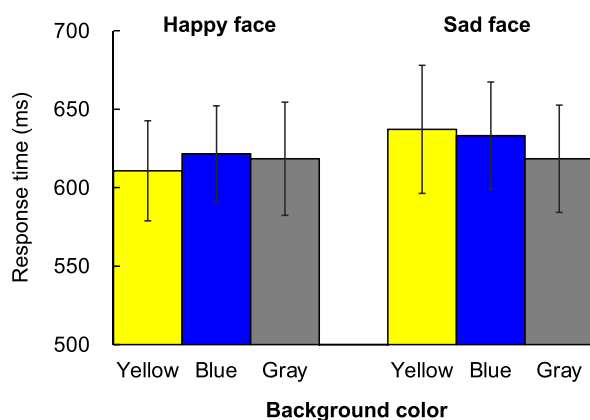
3.2. Results

3.2.1. Number of error response

GLMM was performed on number of error responses in a manner similar to Experiment 1. The only difference was use of a log link function based on minimization of the Akaike information criterion. Intercept was significant ($\chi^2(1) = 7.61$, $p = .006$). There were no significant effects of Emotion ($\chi^2(1) = 0.04$, $p = .834$) and Color ($\chi^2(2) = 3.90$, $p = .142$) or their interaction ($\chi^2(2) = 1.72$, $p = .423$). As the number of error responses per condition (Median = 1, IQR = 0–1) was very small, the null results may be due to the floor effect.

3.2.2. Response time

A median 6.51% of the trials (IQR 5.08–7.81) were excluded from the following analysis based on the same criteria as in Experiment 1. The results for response time are summarized in Figure 3. We did not find significant main effects of Emotion ($F(1, 18) = 1.59$, $p = .224$, $\eta_p^2 = .081$) and Color ($F(2, 36) = 1.17$, $p = .323$, $\eta_p^2 = .061$) or their interaction ($F(2, 36) = 2.45$, $p = .101$, $\eta_p^2 = .120$).

Figure 3. Mean response time in Experiment 2. Error bars represent 95% confidence interval.

3.3. Discussion

Following the results of Experiment 1 suggesting that a yellow background promoted judgment of happy-face stimuli when they were presented simultaneously, Experiment 2 investigated whether a similar effect is observed when color precedes facial stimuli. The analysis of the number of error response again revealed no effect of color or facial expression. Contrary to Experiment 1, the analysis of response time did not reveal main or interactive effects of color and facial expression, including the facilitative effect of yellow on happiness judgment. These results suggest that background color can affect facial expression judgment when the color and facial stimuli are concurrently presented but not when the color precedes the facial stimuli.

4. General discussion

4.1. Yellow–happiness, but not blue/gray–sadness, association affects emotional judgment

The first aim of the present study was to examine whether colors metaphorically associated with happiness and sadness can affect judgment of happiness and sadness in facial stimuli. Experiment 1 suggested that yellow, which has been thought to be associated with happiness, facilitates judgment of happy facial expression, which is consistent with previous findings (Ikeda, 2020; Jonauskaite et al., 2020b). However, although we expected that blue and/or gray would be associated with sadness and consequently facilitate judgment of sad faces according to previous findings (Fetterman et al., 2012; Ikeda, 2020; Jonauskaite et al., 2020b), the results did not support our hypothesis. It was suggested that the yellow–happiness association represented in the human mind may modulate emotional processing, such as judgment of facial expressions, while the blue/gray–sadness association may not.

There are two potential accounts for why blue and gray backgrounds did not affect facial expression judgments. First, according to the conceptual metaphor theory, "happiness is light" (Safarnejad et al., 2014; Yu, 1995), whereas "sadness is dark" (Forceville and Renckens, 2013). The lightness–happiness association is observable in phrases such as "feeling bright" and "bright future" in English and Japanese (i.e., the future is expected to be happy and successful). On the other hand, the darkness–sadness association can be seen in words such as "gloomy" and "*kurai*" (in Japanese), which express both optical darkness and a depressive mood. Thus, the contrast of happiness and sadness can be interpreted not only as contrastive emotional valence but also as contrastive brightness. Yellow can be a symbolic color of the concept of brightness, as it is usually used to depict something bright (e.g., light bulbs and stars). Therefore, our results can also be interpreted as suggesting that yellow facilitates judgment of happiness because yellow activates a lightness–happiness metaphorical association rather than because of the yellow–happiness association. On the other hand, gray and blue did not affect judgments of sadness because they might not be symbolic colors of the darkness and thus did not activate the darkness–sadness association. In this case, darker gray and blue backgrounds might be better able to affect the sadness judgment. Future studies should examine this account by independently manipulating luminance (i.e., bright or dark) and hue (i.e., yellow, blue, or gray).

Second, the difference between the two associations we examined could be explained by whether they were learned linguistically or perceptually. Although there are few linguistic expressions in Japanese in which yellow is used to describe happiness, a metaphorical association between yellow and happiness can be learned from visuo-perceptual experiences in which one perceives yellow co-occurring with sunshine and warmth and feels happiness and joy (Jonauskaite et al., 2019; Jonauskaite et al., 2020b). In contrast, the association of blue and gray with sadness may not be shaped from perceptual experiences, as we rarely find blue and gray in our environment under sad situations, and sad faces do not look bluish or grayish. Nevertheless, blue and gray are often used in

Japanese to describe sadness and depressed states. Therefore, to speculate, visuo-perceptual associations between sadness and blue and gray are weaker than those between happiness and yellow and are unlikely to promote judgment of sadness. In partial support of this speculation, Tillman et al. (2018) suggested that metaphorical representation, such as a mental timeline (i.e., past on the left, future on the right), is constructed more strongly by perceptual experiences than by linguistic input.

4.2. Simultaneous and serial presentations of color and emotional stimuli

Our second aim was to compare the effect of color on judgment of facial expressions between a condition in which a colored background and facial stimuli were presented simultaneously and one in which the colored background preceded the facial stimuli. In Experiment 1, that with the simultaneous presentation, happiness judgment was enhanced by a yellow background, whereas in Experiment 2, that with the serial presentation, an effect of color was not observed. We propose two potential explanations for these results. First, temporal proximity between presentations of color and facial stimuli might be important for the effect. The color–emotion association has been suggested to be stronger when color and emotion are perceptually experienced simultaneously (Jonauskaite et al., 2020a). Therefore, the simultaneous presentation of color and facial stimuli in a Stroop-like manner may be effective in enhancing the processing of the facial expression because it might better reproduce a daily situation that involves the co-occurrence of color and emotion.

Second, color perception may have an influence on the early stage of recognition of facial expressions (Sivananthan et al., 2021). In face perception, low-level features of the face such as shape and configuration are analyzed, followed by analysis of emotion in the face, and these analyses interact with each other to facilitate recognition of the emotion in facial expressions (Bruce and Young, 1986; Haxby et al., 2000). To speculate, color perception may have an influence during either facial feature analysis or emotional content analysis, or possibly during both. If a face has features representative of a certain emotion, and the perceived color matches that emotion, then the judgment of emotion expressed in the face will be facilitated. This could be a reason why the onset of color and facial stimuli must be temporally proximal for the facilitative effect to occur. This hypothetical explanation requires detailed testing in future studies.

One may expect that stronger effects of color–emotion associations occur in serial presentation as color stimuli are presented longer than in simultaneous presentation. Yet, our results do not reflect this and are inconsistent with previous studies showing effects of color–emotion association in serial presentation (e.g., Young et al., 2013). There are three possible explanations for this discrepancy. First, Young et al. (2013) studied a red–anger association. It has been suggested that the association between anger and red is stronger than between happiness and yellow due to its higher frequency of occurrence (Jonauskaite et al., 2020b). Given this, in Young et al. (2013), the effect of the congruency of the red–anger association was strong enough to be maintained during serial presentation of red and an angry face and promote facial expression judgment. Second, the difference in the length of the temporal interval between color and facial stimuli presentation. The interval in the present study was one second, while that in Young et al. (2013) was 1.5 s. It is unclear that this difference facilitates or inhibits the effect, although future studies can investigate whether temporal proximity between color and emotional stimuli interacts with the effect of color–emotion association on the recognition of facial expressions. Finally, the native language of the participants in the present study was Japanese, while that of participants in previous studies was English. The farther the linguistic distance between languages, the less similar the patterns of color–emotion associations are (Jonauskaite et al., 2020a). Given that Japanese is among languages with the farthest interlingual distance from English (Chiswick and Miller, 2005), the tendency to associate a color with an emotion may differ between the present and previous studies. Thus, future cross-language studies with participants whose native

languages are linguistically closer to English, such as Germanic languages including Afrikaans, Swedish, and Norwegian, would be beneficial (Chiswick and Miller, 2005).

4.3. Limitations

The present study has four limitations of note. First, it only investigated happiness, sadness, and (some of) their associated colors in Japanese students. There are various color–emotion associations other than those examined in the present study (Gilbert et al., 2016; Jonauskaite et al., 2020b), and cross-language differences may exist (Jonauskaite et al., 2020a). Moreover, previous studies investigating, for example, the red–anger association (Young et al., 2013) has shown the effect of color on facial expression judgment even in serial presentation of stimuli, in contrast to the present study. Thus, to replicate and generalize the present findings, other color–emotion associations need to be examined in multiple cultural groups.

Second, the present study investigated only the accuracy and speed of judgment of facial expressions. It remains unclear whether and how the perceived intensity of emotions expressed in facial stimuli is modulated by metaphorically (un)matched colors.

Third, almost all the participants in the present study were female, thus our findings may not be generalizable to males. Moreover, a previous study suggested that females viewing emotionally ambiguous faces of both sexes were more likely to judge the male faces as showing negative emotion (Gil and Le Bigot, 2015). It is possible that our female participants perceived both happy and sad male faces in our experiments as relatively negative; a bias that contaminated the results. We cannot test this hypothesis as our sample included only one male participant. Future investigations on effects of viewer's and actor's gender with a more balanced sample would be fruitful.

Finally, we used fully saturated yellow and blue and gray, an achromatic color, as our stimuli. Many studies on the color–emotion association have also only used focal colors (e.g., Ikeda, 2020; Young et al., 2013). However, some studies have suggested that saturation and other properties of color contribute to emotional processing. For example, the arousal and valence of emotional states induced by colored visual stimuli can be modulated by the saturation, lightness, and hue of the stimuli (Wilms and Oberfeld, 2018). It is suggested that not only saturation but also lightness of color is an important factor in the effect of color–emotion association on emotional processing. However, although fully saturated yellow is lighter than fully saturated blue, we did not control the lightness of color stimuli; consequently, our results might be affected by the potential influence of lightness. Nevertheless, when controlling for lightness of blue and yellow, the fully saturated blue will be lightened, and/or the fully saturated yellow will be darkened. Given that light blue can be associated more with happiness than with sadness (Schloss et al., 2020), experiments using light blue with controlled lightness may be inappropriate to investigate colors associated with sadness. Moreover, given that dark yellow is unlikely to be perceived as "yellow" (Schloss et al., 2020), experiments using dark yellow are also inappropriate to test the effect of the yellow–happiness association. Therefore, color stimuli in the present study were fully saturated focal colors with different lightness. Future studies should investigate whether the categorical property of color (i.e., hue) *per se* is a key determinant of the effects of the color–emotion association on emotional processing as well as whether saturation and lightness continuously modulate those effects.

5. Conclusions

We found a facilitating effect of yellow on judgment of happiness, while neither blue nor gray facilitated judgment of sadness. This finding suggests different influences of the color–emotion association on human cognition; the association of sadness with blue and gray could be weak and thus not affect emotional judgment. In addition, the effect of yellow was only observed when the color and facial stimuli were presented

simultaneously, suggesting that temporal proximity is critical for the effect of the color–emotion association on emotional judgment.

Declarations

Author contribution statement

Asumi Takei: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Shu Imaizumi: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

Data availability statement

Data associated with this study has been deposited at Open Science Framework under the url https://osf.io/tygcb/.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

None.

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