Psychology of Aesthetics, Creativity, and the Arts
2016, Vol. 10, No. 3, 360–371

1931-3896/16/$12.00 http://dx.doi.org/10.1037/a0040274

The Effects of Image Hue and Semantic Content on Viewer's Emotional Self-Reports, Pupil Size, Eye Movements, and Skin Conductance Response

Arvydas Kuzinas
Mykolas Romeris University

Nicolas Noiret and Renzo Bianchi
Université de Franche-Comté, Besançon, France

Éric Laurent
Université de Franche-Comté, Besançon, France and Maison des Sciences de l'Homme et de l'Environnement, CNRS/UFC/UTBM, Besançon, France

A study was conducted in order to examine the emotional effects of content and hue interacting in the same image. To achieve this goal, self-reported (based on Self-Assessment Manikin [SAM] scale), physiological (pupil diameter and skin conductance response), and behavioral (eye movement) measures were used in response to a set of photographs selected from the International Affective Picture System (IAPS). Each of them was a combination of 1 type of content (natural or urban) and 1 type of image version (original, grayscale, green, or red). The results revealed that participants' emotions were dependent on specific contents, hues, and content × hue interactions. The natural content elicited more positive and less arousing emotions compared to the urban one. Green images were less arousing compared to red ones, and original images elicited the most pleasant emotions. Moreover, green was the only hue for which valence effects of content were observed—the natural content–green color combination elicited more positive emotions compared to the urban content–green color combination. Results emerging from the different measures are connected to each other and interpreted in the framework of cognitive fluency. Pupil dilation on the one hand, and eye movements and fixations on the other hand, which respectively provided data on vegetative responses and visual search strategies, were often found to embody the emerging emotional experience.

Keywords: color, emotion, hue, image, semantic content

Any image is composed of many different attributes, such as color, size, or shape. These attributes and their arrangements allow us to distinguish an apple from an orange, or a diagram from a piece of art. The color of an object is a critical attribute that has three main functions (Zettl, 2005): informational, compositional, and expressive. These functions involve a variety of psychological processes. For example, color has effects on memory (McKelvie, Sano, & Stout, 1994; Spence, Wong, Rusan, & Rastegar, 2006) and attention (Camgöz, Yener, & Güvenç, 2004; Lapė & Masiliūnaitė, 2001). The effect of color on our emotions is especially noticeable. Indeed, color not only conveys information, it also has affective value for the viewer (Boyatzis & Varghese, 1994; Detenber, Simons, & Reiss, 2000; Valdez & Mehrabian, 1994; Zentner, 2001; Zettl, 2005). That is one reason why colors have been extensively used in various types of visual art, entertainment shows, information presentation, advertising, or marketing. Some examples include choosing specific colors for brand logos (Bottomley & Doyle, 2006), candies (Walsh, Toma, Tuveson, & Sondhi, 1990), as well as paintings (Polzella, Hammar, & Hinkle, 2005) or photographs (Detenber & Winch, 2001). Most of the aforementioned studies agree on the fact that the expected emotional impact is obtained only when a specific color is associated with a specific content. The present study aimed at expanding the understanding of the link between color and content, with special emphasis on the effects of image hue on the viewer's emotions. Most previous color studies (Boyatzis & Varghese, 1994; Gao & Xin, 2006; Ou, Luo, Woodcock, & Wright, 2004; Terwogt & Hoeksma, 1995; Valdez & Mehrabian, 1994; Zentner, 2001) used simple patches, thus limiting the practical application of the results. In the current study, we were interested in the processing of more complex stimuli, and investigated the emotional activity emerging from the interactions between stimulation color and content.

Definition of Emotion

Emotion, in this paper, is conceived as a response of the organism to a specific event that is perceived as important. The main function of emotion is to prepare the organism to act in response

This article was published Online First May 16, 2016.
Arvydas Kuzinas, Department of Psychology, Mykolas Romeris University; Nicolas Noiret and Renzo Bianchi, EA 3188 Laboratoire de Psychologie, Université de Franche-Comté, Besançon, France; Éric Laurent, EA 3188 Laboratoire de Psychologie, Université de Franche-Comté, and UMSR 3124 Maison des Sciences de l'Homme et de l'Environnement, CNRS/UFC/UTBM, Besançon, France.
The first author would like to thank the Embassy of France in Lithuania for making this research possible.
Correspondence concerning this article should be addressed to Arvydas Kuzinas, Department of Psychology, Mykolas Romeris University, Ateities street 20, LT-08303, Vilnius, Lithuania, or to Éric Laurent, Laboratoire de Psychologie EA 3188, University of Franche-Comté, 30 rue Mégevand, 25030 Besançon Cedex, France. E-mail: kuzinasa@gmail.com or eric.laurent@univ-fcomte.fr

to significant stimuli (Bradley, Codispoti, Cuthbert, & Lang, 2001; Bradley, Codispoti, Sabatinelli, & Lang, 2001; Bradley & Lang, 2007; Frijda, 1986; Sander & Scherer, 2009; Lang & Bradley, 2010). Threatening stimuli activate the defensive motivational system and thus prepare the organism for an avoidance reaction. Events associated with positive survival values activate the appetitive system and approach behaviors. Most generally, emotions are described in terms of valence and arousal (Lang & Bradley, 2010). Valence refers to the negative or positive value of a stimulus for the organism. Arousal refers to the strength of the activation of the emotional systems of the organism. Emotional arousal depends on the perceived importance of the event. Any visual stimulus has many attributes that can convey significance. Content and color hue are critical to the emotional effects of a given picture.

The Emotional Effects of Image Content

Several studies have shown that emotions can be influenced by the content of pictures (Bernat, Patrick, Benning, & Tellegen, 2006; Bradley, Codispoti, Cuthbert, et al., 2001; Bradley, Miccoli, Escrig, & Lang, 2008). For example, largest skin conductance and increased pupil diameter were registered while watching erotic or threat-related stimuli (compared, for instance, to household objects), which are associated with higher survival value and, thus, are more arousing. Studies have also demonstrated that the emotional content of pictures can influence eye movements (Bradley, Houbova, Miccoli, Costa, & Lang, 2011; Bradley, Keil, & Lang, 2012; Carniglia, Caputi, Manfredi, Zambarbieri, & Pessa, 2012; Niu, Todd, & Anderson, 2012; Nummenmaa, Hyönä, & Calvo, 2006; Pilarczyk & Kuniecki, 2014). For instance, Bradley and colleagues (2011) have shown that the number of fixations recorded while watching pictures with hedonic contents (i.e., pleasant or unpleasant) was higher than while watching neutral pictures. The duration of a fixation was lower on hedonic contents than on neutral content, whereas the scanpath was longer. Niu and colleagues (2012) have also shown that the proportion of fixations allocated to affectively salient regions (i.e., "participant-identified emotionally meaningful regions of each image," p. 1) was associated with higher ratings of arousal for both negative and positive pictures. As for skin conductance and pupil size, arousing scenes prompt specific eye movement patterns that are consistent with the appetite and defensive motivational systems described above (Bradley et al., 2011, 2012). Emotional visual cues activate appetitive or defensive systems, enhancing information seeking, as indexed by a greater number of fixations, briefer fixation duration and a longer scanpath on emotional pictures compared to neutral pictures.

Two categories of content, which differ greatly in evoked emotional response, are natural and urban. Natural pictures are preferred to urban ones and are considered more beautiful (van den Berg, Koole, & van der Wulp, 2003). The likely reason is that images with natural content are cognitively processed faster compared to pictures depicting artificial content (Rousselet, Joubert, & Fabre-Thorpe, 2005). Moreover, natural environments have more restorative effects on cognitive functioning (Berman, Jonides, & Kaplan, 2008), because of comparably lesser amounts of the directed attention it usually requires (an urban environment needs constant observation of the environment and filtering "junk" information).

The Emotional Effects of Image Hue

Different hues can have different emotional values. Several studies showed that colored pictures elicit more positive and arousing emotions compared to monochrome pictures (Detenber et al., 2000; Detenber & Winch, 2001). Single hues have also been points of interest. Some hues (e.g., blue, green) are often associated with positive emotions and others (brown, shades of gray) with negative emotions (Boyatzis & Varghese, 1994; Burkitt, Barrett, & Davis, 2003; Valdez & Mehrabian, 1994).

Recently, cognitive–emotional effects of colors have been investigated by employing eye-tracking techniques, showing that not only does color have effects on visual search through the influence of emotion, but it also has complementary effects on visual search as a function of its diagnostic features for the task at hand. El Sadek and colleagues (2013) asked participants to describe their impressions toward plants of different foliage colors while their eye movements were recorded. Authors found the participants had lower number of fixations and lower fixation duration on dark green—associated with calmness and relaxing—in comparison with green-white, green-yellow, bright green or red plants. On the other hand, Frey, Honey, and König (2008) recorded eye movements of participants while they freely viewed colored or grayscale versions of the same pictures depicting different "nonemotional" scenes (e.g., flower, fractals, manmade, rainforest, etc.). They found that eye fixation locations differed between colored and grayscale versions. Moreover, the influence of color features of scenes on eye fixation locations depended on the type of scenes. These findings suggest that color is a salient visual cue only if it is a potential diagnostic feature to recognize the stimulus (e.g., color is not crucial to object grasping whereas it is relevant in rainforest environment to collect edible fruits or to avoid predators). Therefore, it is critical to better understand how content and color interact to predict various effects of colors on both cognitive and emotional processes as a function of their presentation context.

Potential Interactions Between Colors and Image Content

To date, the effects of content–color interaction on emotion have received little consideration. A few researchers investigated the issue by contrasting color and grayscale pictures. Detenber and Winch (2001) studied newspaper photographs and found that colored photographs were more arousing than grayscale ones, independently of the content. Nevertheless, the magnitude of the difference turned out to be significantly influenced by specific content. For instance, in pictures with blood, the difference in question was pronounced, while it was small with "tragic" photographs (where grief, sadness, etc., were depicted). Similar results were found with valence dimensions: color photographs with blood were perceived as the most negative.

The interaction of color with content was also demonstrated comparing color and grayscale versions of famous paintings (Polzella et al., 2005). Two categories of contents were studied: landscapes (including both natural and manmade objects) and portraits. Results showed that landscapes were evaluated as less beautiful, less pleasing, and less relaxing when displayed in grayscale. An opposite effect was found with portraits.

In these examples chromatic and achromatic versions of the same images were compared. However, the observed emotional effects suggest that care must also be taken while studying more specific hues. Since hue and content generally coexist in the same image, it is important to understand how these two attributes interact.

In sum, previous studies either compared colored and grayscale versions of the same photograph (Detenber & Winch, 2001) or examined plain patches of several different hues (Boyatzis & Varghese, 1994; Gao & Xin, 2006; Ou et al., 2004; Terwogt & Hoeksma, 1995; Valdez & Mehrabian, 1994; Zentner, 2001). This makes it difficult to integrate the results from these two categories of research. In particular, it is hard to explain the effects of grayscale pictures, even if they are very commonly used in media. It is unknown whether such a version of pictures is distinct from the original version due to a lack of saturation or to an unnatural appearance. Therefore, it is important to study how different contents interact with single hues, because humans usually process complex images rather than single hue patches. Beyond the theoretical perspective, the question has also practical relevance. For instance, designers often have to make decisions that are not about whether a picture should be colored or grayscale, but rather about which specific dominant hue should be used for a specific content (e.g., for marketing purposes).

The Present Study

The aim of the present study was to examine behavioral, physiological, and subjective emotional responses to pictures associated with different contents and hues, and to measure to what extent those emotional responses to specific contents are also dependent on hue. We analyzed both subjective experience, physiological response, and oculomotor behavior. For physiological measures, skin conductance response and pupil dilation were chosen, because they are well-suited physiological methods for measuring emotional arousal (Bradley et al., 2008; Lang & Bradley, 2010). Moreover, building on previous research suggesting that (a) color can influence both fixation number and fixation duration (El Sadek et al., 2013), and (b) emotional arousal has been found to increase scanpath length and fixation number and to decrease fixation duration (Bradley et al., 2011), we also recorded eye movement data.

Four image versions (original, grayscale, red, and green) and two types of contents (natural and urban) were selected for the experiment. This variety represents stimuli from opposing categories, and also allows a comparison of results from different types of studies.

Several predictions were made. First, urban images should be more arousing compared to natural ones due to the restorative function of natural surroundings (Berman et al., 2008). Second, emotional reactions to different hue versions should also be different. Green and grayscale versions would evoke the least arousing emotions compared to other versions. This was expected, because green and gray versions of pictures have often been evaluated as “calming” or “dull” (Boyatzis & Varghese, 1994; Clarke & Costall, 2008; Kaya & Epps, 2004). Moreover, the saturation value of grayscale is 0, which is different from all other color types, and it is known that lower saturation is associated with lower arousal (Gao & Xin, 2006; Ou et al., 2004; Valdez & Mehrabian, 1994). On the other hand, red and original versions of pictures should be the most arousing. Red can be associated with survival (e.g., color of blood). The original color version is multihue and was reported as relatively arousing in previous studies (Detenber et al., 2000; Detenber & Winch, 2001). Third, hue effects should be influenced by content. Due to the prevalence of green–natural combinations, there should be significant differences in green hue evaluations between natural and urban contents. Fourth, due to the prevalence of these specific combinations and the combined effects of single attributes, it was most likely that green–natural pictures would be associated with the lowest arousal (i.e., green hue and natural content are not only very frequent combinations, each of them taken separately should be associated with low arousal), while original–urban, for the opposite reasons, would evoke the most arousing emotions.

The test of the hypotheses should contribute to a better understanding of the role of content, hue, and content × hue interactions in relations with the dynamics of perceptual–emotional experience and behaviors.

Method

Participants

Twenty-one students (12 females) from the University of Franche-Comté participated in the study (Mean age = 23.86 years, *SD* = 4.127). Each participant had normal or corrected-to-normal visual acuity and normal color vision. No post hoc exclusions due to vision problems were needed, since all participants met the minimal performance criteria upon inclusion.

Materials

Twelve photographs were selected from the International Affective Pictures System (IAPS; Lang, Bradley, & Cuthbert, 2008). Six of them represented natural content (IAPS image numbers 5040, 5120, 5532, 5750, 5780, 5814) and six represented urban content (IAPS image numbers 7242, 7501, 7510, 7546, 7650, 9468). Photographs were selected by matching their valence, arousal, and dominance ratings based on the norms of the IAPS (such that pictures in the natural content condition would have similarly rated counterparts in the urban content condition). Moreover, one additional criterion for selection was that SAM arousal value should be average (from 4 to 6). This was important to avoid effects of very high or low arousal, which could hinder noticing changes due to hue. Each photograph had four versions: original (unmodified photograph), grayscale, green (green tint applied to grayscale version) and red (red tint applied to grayscale version; see Table 1). All modifications were performed by GIMP 2.6 open-source image manipulation software. Overall, there were 48 different images. Additionally, two photographs that included both natural and urban content, were used for the practice trials (IAPS image numbers 7491 and 7530, the former was presented in original color and the latter was converted to grayscale).

Apparatus

Pictures were presented on a 19-inch ASUS computer screen with a screen refresh rate of 60 Hz. The distance between the

Table 1
Averaged HSV Values of Individual Manipulated Images (Original, Grayscale, Red, and Green Versions) and Mean Values for Each Version and Content

Image contents	IAPS No.	Original			Grayscale			Red			Green		
		H	S	V	H	S	V	H	S	V	H	S	V
Natural	5040	25	72	50	—	0	32	1	64	44	120	64	45
	5120	46	51	58	—	0	43	0	58	58	120	59	58
	5532	1	53	47	—	0	35	1	59	46	119	59	46
	5750	77	73	40	—	0	26	0	59	35	104	60	35
	5780	129	31	55	—	0	49	1	42	57	110	42	57
	5814	43	29	58	—	0	52	2	47	62	118	47	62
	Mean	53.5 (44.69)	51.5 (19.03)	51.33 (7.09)	—	0 (0)	39.5 (10.17)	.83 (.75)	54.83 (8.42)	50.33 (10.33)	115.17 (6.65)	55.17 (8.61)	50.5 (10.21)
Urban	7242	9	24	53	—	0	48	0	41	56	116	41	56
	7501	9	72	35	—	0	22	1	62	31	111	63	31
	7510	27	65	52	—	0	36	0	58	48	118	59	48
	7546	213	25	50	—	0	47	3	44	53	112	45	53
	7650	65	15	50	—	0	47	0	52	60	120	53	61
	9468	292	23	62	—	0	56	1	43	68	119	43	68
	Mean	102.5 (120.59)	37.33 (24.5)	50.33 (8.73)	—	0 (0)	42.67 (11.96)	.83 (1.17)	50 (8.7)	52.67 (12.58)	116 (3.74)	50.67 (9.07)	52.83 (12.7)
All	Mean	78 (90.4)	44.42 (22.19)	50.83 (7.6)	—	0 (0)	41.08 (10.72)	.83 (.94)	52.42 (8.54)	51.5 (11.04)	115.58 (5.16)	52.92 (8.75)	51.67 (11.06)
	Content	All versions											
		H	S	V									
Mean	Natural	42.38 (52.7)	40.38 (26.07)	47.92 (10.2)									
	Urban	54.83 (79.24)	34.5 (24.66)	49.63 (11.62)									

Note. In parentheses = standard deviations. H = hue; S = saturation; V = value/luminance; IAPS = International Affective Picture System.

monitor and the participant was about 60 cm. Due to the differences in resolution between IAPS photographs (1024 × 768) and computer screen (1280 × 1024), all photographs were presented with a gray background surrounding them. Stimulus presentation and timing was controlled by Inquisit 3 software (Millisecond Software, Seattle, WA) running on an IBM-compatible computer.

Pupil diameter and eye movements were recorded using an ASL EYE-TRAC 6 remote optics eye tracking system (Applied Science Laboratories, Bedford, MA) with a sampling rate of 60 Hz and a spatial resolution of .25° of visual angle. Pupil and corneal reflection enabled gaze recognition, while head movements were monitored by a head tracker system. The latter uses a camera as well as face recognition algorithms to allow relatively free movements of the participant's head. Eye behaviors were considered as fixations when they were within 1° of visual angle for more than 100 ms.

Skin conductance data was collected using an MP36R data acquisition unit and AcqKnowledge 4.1 software (BIOPAC Systems, Inc., Goleta, CA). Two Ag-AgCl electrodes, filled with conductive paste GEL101, were placed on volar surfaces of distal phalanges of the index and middle fingers of the nondominant hand.

Self-report ratings of emotions were collected using the Self-Assessment Manikin (SAM) scales, ranging from 1 to 9 (Bradley & Lang, 1994). The method is based on graphic figures, which serve as a reference for participants to evaluate their own emotional response to images. There are three groups of figures, which represent valence, emotional arousal, and dominance dimensions. Valence is associated with the feelings of pleasure (from positive to negative), arousal describes the strength of emotion (from aroused to calm), while dominance is related to the magnitude of control of emotional experience (from dominated to dominant). The SAM figures were shown on a computer screen and participants had to perform evaluations by using a computer mouse.

Procedure

The experiment took place in a medium-illuminated, soundproof, laboratory room (1.80 × 1.72 m), where illumination was kept constant throughout the experiment. Upon arrival, participants were introduced to the laboratory and after giving their consent to participate in the experiment they were seated in the marked place in front of the computer screen. Then the electrodes to measure skin conductance were placed and the calibration of the participant's left eye for pupil data recording was run.

At the beginning of the experiment, written instructions were presented on the computer screen and a training session with two practice images was run in order to make sure that participants understood the instructions correctly. Data from the training trials were not included in the analyses. Participants were instructed to watch images for as long as they were presented and after they disappeared from the screen, to rate the feelings that were felt when looking at the image. It was stressed that participants had to rate their own feelings and not the content of the pictures.

At the beginning of every trial, a white fixation dot was shown for 1 s in the middle of the screen with a gray background (see Figure 1). Then, a picture was presented for 6 s. It was followed by a fixation dot for 1 s, and later by digitalized SAM scales on which participants made their self-reported evaluations. Between two trials, a gray blank screen was displayed. The starting of a new trial was triggered by the experimenter who pressed the spacebar of a keyboard. This gray blank screen served as a calming phase for establishing the baseline period for skin conductance response. Therefore the duration was variable as a function of participant skin conductance response. In addition, this time was also used for eye tracking corrections if those were needed (in order to compensate for slight movements of participant's head). No data collected during this empty gray blank screen phase were used in later analysis.

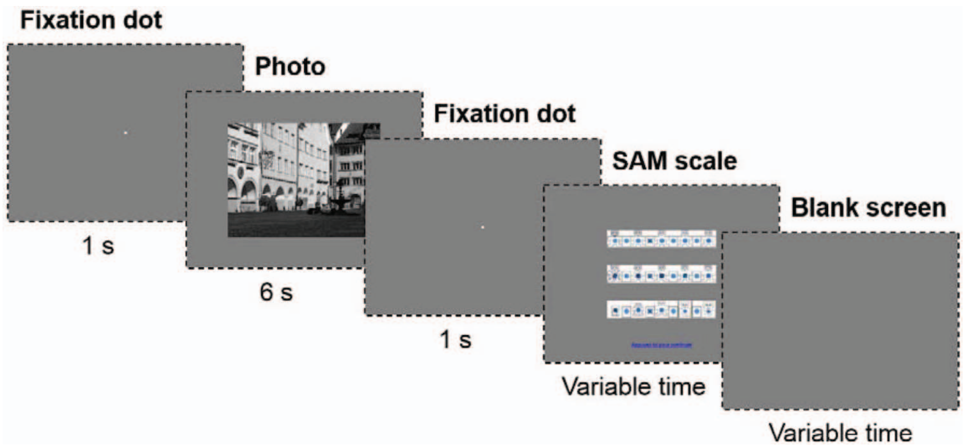

Figure 1. Timing and material corresponding to one trial (the photo is for illustrative purposes only—the latter was not used in the study and was taken by Arvydas Kuzinas). See the online article for the color version of this figure.

The presentation order was random, and each participant individually viewed all images. At the end of the experiment, participants were asked to answer questions about their age, gender, and vision. The total duration of the experiment was 20–30 min.

Data Reduction

Since images were presented for 6 s, the pupillary response to the presented picture was calculated as the average size of the pupil during the 2–6 s period after the stimulus onset. The first 2 s of picture presentation were not included in order to avoid recording the pupil constriction in response to light reflex. In cases where the pupil was unavailable due to blinking, linear interpolation, based on the pupil size before and after the blink, was used to estimate missing pupil size.

Due to slower reactivity of skin conductance response, the difference between the maximum signal during 1–6 s after stimuli onset and the mean of 1-s period before the stimuli onset (baseline) was calculated. In order to normalize the data, square-root transformation was computed.

As regards eye-tracking measures, the total number of fixations was calculated by summing up the number of fixations within a picture. The mean fixation duration was computed as the mean duration of each fixation within each picture. The mean length of saccades corresponded to the mean distance between successive fixations within each picture. The length of the whole scanpath was calculated by summing up distances between successive fixations within each picture. For each of these measures, the mean was calculated over all pictures for each category.

Data Analysis

As the luminance of images influences the pupillary response, the luminance values of different pictures were compared. An average luminance of every image was calculated (based on hue, saturation, and value [HSV] characteristics). Then, analysis of variance with factors Content (two levels: natural, urban) and Hue (four levels: original, grayscale, red, green version of photograph) was conducted to compare the mean luminance of each image category in preliminary control analyses. Similarly, the average saturation values of every image were compared in order to evaluate the possible impact of this color characteristic.

After that, SAM scales were recoded so that higher values indicated more positive valence, higher arousal, and greater feelings of self-dominance. Multiple 2 (Content: natural vs. urban) × 4 (Hue: original, grayscale, green, red) analyses of variance were computed for each of the following dependent variables: valence rating; arousal rating; dominance ratings; physiological measures of skin conductance (square-root of original value in microsiemens); pupil diameter (in millimeters); eye movement data (number of fixations, mean fixation duration [in seconds], mean length of saccades [in degrees of visual angle], length of the whole scanpath [in degrees of visual angle]). The ANOVAs were followed by Tukey's HSD multiple post hoc comparisons. The alpha level for significance was set at $p < .05$.

Results

Preliminary Analyses

Luminance. There were no significant differences in mean luminance between natural and urban photographs: $F(1, 40) = 0.310$, $MSE = 112.963$, $p = .581$, $\eta_p^2 = .008$, $1 - \beta = .06$ (see Table 1). There was no main effect of hue on luminance: $F(3, 40) = 2.804$, $MSE = 112.963$, $p = .052$, $\eta_p^2 = .174$, $1 - \beta = .44$. Lastly, there were no significant differences between different Content × Hue combinations: $F(3, 40) = 0.091$, $MSE = 112.963$, $p = .965$, $\eta_p^2 = .007$, $1 - \beta = .06$.

Saturation. Saturation of different images varied (see Table 1). The grayscale version of each picture always had a saturation value of 0, while the red and green versions were almost identical in the same content and very similar between different images (since they were both created from the grayscale version, it was possible to equalize the saturation value during manipulation). The biggest variability between different images was in the original version condition. However, there were no significant differences in mean saturation between natural and urban pictures: $F(1, 40) =$

2.618, MSE = 158.196, p = .114, η_p^2 = .061, 1 – β = .14. As expected, there was a main effect of hue on saturation: $F(3, 40)$ = 48.402, MSE = 158.196, p = .001, η_p^2 = .784, 1 – β = 1, but the only version which significantly differed from all others was grayscale (compared to original: $p < .001$, d = 2.83; red: $p < .001$, d = 8.68; green: $p < .001$, d = 8.55). This is not surprising, since its saturation value was always 0. If saturation was compared only among red, green, and original, there were no significant differences: $F(2, 30)$ = 1.294, MSE = 210.928, p = .289, η_p^2 = .079, 1 – β = .18. Lastly, Content × Hue interaction was not significant: $F(3, 40)$ = 0.672, MSE = 158.196, p = .575, η_p^2 = .048, 1 – β = .12. This shows that all stimuli were similar in both luminance and saturation characteristics (except the grayscale version, which had a constant saturation of 0).

Self-Reported Measures

Valence. A significant main effect of content was seen: $F(1, 20)$ = 4.372, MSE = .716, p = .049, η_p^2 = .179, 1 – β = .51. Natural pictures were rated as evoking more positive emotions compared to urban ones (see Table 2). Moreover, a significant main effect of hue was observed: $F(3, 60)$ = 21.007, MSE = 1.09, p = .001, η_p^2 = .512, 1 – β = 1. Pairwise comparisons showed that the only significantly different image version was the original color one. This version of the picture evoked significantly more positive emotions than grayscale ($p < .001$, d = 1.75), red ($p < .001$, d = 1.94) or green ($p < .001$, d = 1.81) version. There were no other statistical differences (see Table 3). Interaction between content and hue was also significant: $F(2.256, 45.122)$ = 7.269, MSE = 0.42, p = .001, η_p^2 = .267, 1 – β = .98 (Mauchly's test indicated that the assumption of sphericity had been violated [chi-square = 17.214, p = .004]; therefore, degrees of freedom were corrected using Hyunh-Feldt estimates of sphericity [epsilon = .752]). Pairwise comparisons indicated that the natural–original combination was evaluated as evoking significantly more positive emotions compared to all other combinations (natural–grayscale: $p < .001$, d = 1.73; natural–red: $p < .001$, d = 2.01; natural–green: $p < .001$, d = 1.58; urban–grayscale: $p < .001$, d = 1.81; urban–red: $p < .001$, d = 2.06; urban–green: $p < .001$, d = 2.12), except the urban–original (p = .17, d = 0.57). The urban–original combination was also evaluated as significantly more positive than all other combinations (natural–grayscale: $p < .001$, d = 1.14; natural–red: $p < .001$, d = 1.49; natural–green: $p < .001$, d = 0.97; urban–grayscale: $p < .001$, d = 1.22; urban–red: $p < .001$, d = 1.43; urban–green: $p < .001$, d = 1.60), except natural–original. This shows that the original hue differed from other hues in both contents. Moreover, the natural–green combination evoked more positive emotions than urban–green (p = .001, d = 0.79). There were no other differences between natural and urban content in other photograph versions (see Table 4).

Arousal. A significant main effect of content was observed: $F(1, 20)$ = 16.357, MSE = 1.44, p = .001, η_p^2 = .45, 1 – β = .97. Urban pictures evoked significantly more arousing emotions compared to the natural ones (see Table 2). A significant main effect of hue was also revealed: $F(2.218, 44.368)$ = 13.79, MSE = 0.963, p = .001, η_p^2 = .408, 1 – β = .99 (Mauchly's test indicated that the assumption of sphericity had been violated [chi-square = 13.56, p = .019]; therefore, degrees of freedom were corrected using Hyunh-Feldt estimates of sphericity [epsilon = .739]). Pairwise comparisons indicated that the grayscale version was evaluated as evoking less arousing emotions compared to original (p = .004, d = 1.01), red ($p < .001$, d = 1.12) and green (p = .007, d = 0.57) version. Red version was considered as the most arousing compared to original (p = .03; d = 0.47), grayscale ($p < .001$; d = 1.12) and green (p = .02; d = 0.46) version (see Table 3).

Interaction between content and hue was also significant: $F(3, 60)$ = 3.932, MSE = 0.409, p = .013, η_p^2 = .164, 1 – β = .81. Pairwise comparisons showed that the greatest emotional arousal was evoked by red hue images with urban content. This difference was significant, while urban–red combination was compared to natural–original ($p < .001$, d = 1.25), natural–grayscale ($p < .001$, d = 1.40) and natural–green ($p < .001$, d = 0.82), as well as grayscale version in urban content ($p < .001$, d = 0.91). However, there were no significant differences between urban–red and urban–green (p = .17, d = 0.38) or urban–original (p = .99, d = 0.09) combinations. Moreover, the natural–original combination was evaluated as evoking significantly less arousing emotions compared to the urban–original (p = .001, d = 1.15). The original was the only photograph version where two types of content differed. Other significant differences can be seen in Table 4.

Dominance. A significant main effect of content on dominance ratings was observed: $F(1, 20)$ = 14.096, MSE = 0.551, p = .001, η_p^2 = .413, 1 – β = .95. Participants felt significantly less in control when the urban pictures were presented than when the natural were (see Table 2). The effect of hue was also significant: $F(2.221, 44.413)$ = 11.47, MSE = 0.681, p = .001, η_p^2 = .364, 1 – β = .99 (Mauchly's test indicated that the assumption of sphericity had been violated [chi-square = 13.87, p = .017]; therefore, degrees of freedom were corrected using Hyunh-Feldt estimates of sphericity [epsilon = .74]). Pairwise comparisons revealed that

Table 2
Mean Values of Valence, Arousal and Dominance Ratings, Skin Conductance Response, Pupil Size and Eye Movement Data for Images With Different Contents

Image contents	Valence	Arousal	Dominance	Skin conductance	Pupil size	Number of fixations	Mean fixation duration	Mean length of saccades	Length of the whole scanpath
Natural	5.056 (.622)*	4.395 (.989)*	5.212 (1.466)*	.7 (.266)	3.377 (.531)	12.938 (4.082)	.416 (.097)*	3.792 (.789)*	52.514 (18.559)
Urban	4.783 (.629)*	5.144 (1.153)*	4.782 (1.538)*	.685 (.294)	3.338 (.525)	13.071 (3.994)	.388 (.071)*	4.003 (.911)*	57.084 (19.497)

Note. In parentheses = standard deviations. Valence, arousal and dominance are based on SAM scale; Skin conductance is presented after square-root transformation; Pupil size is presented in millimeters; Mean fixation duration–in seconds, Mean length of saccades and length of the whole scanpath are presented in degrees of visual angle.
* comparison of natural versus urban contents is significant at $p < .05$.

Table 3
Mean Values of Valence, Arousal and Dominance Ratings, Skin Conductance Response, Pupil Size and Eye Movement Data for Different Versions of Images

Image colors	Valence	Arousal	Dominance	Skin conductance	Pupil size	Number of fixations	Mean fixation duration	Mean length of saccades	Length of the whole scanpath
Original (a)	6.01 (.682) b, c, d	4.805 (1.097) b, c	5.436 (1.534) c, d	.647 (.298)	3.301 (.514) b, c	13.627 (4.31) d	.363 (.066) c, d	4.169 (.961) b, c, d	60.985 (20.08) b, c, d
Grayscale (b)	4.722 (.783) a	4.155 (.927) a, c, d	5.171 (1.440) c, d	.681 (.315)	3.512 (.559) a, c, d	13.422 (3.954) d	.404 (.089)	3.848 (.826) a	55.003 (17.859) a
Red (c)	4.401 (.956) a	5.337 (1.176) a, b, d	4.655 (1.58) a, b	.694 (.325)	3.366 (.539) a, b, d	12.658 (3.693)	.41 (.099) a	3.81 (.797) a	52.789 (17.24) a
Green (d)	4.545 (.922) a	4.78 (1.232) b, c	4.726 (1.608) a, b	.748 (.290)	3.251 (.509) b, c	12.312 (4.445) a, b	.431 (.119) a	3.763 (.879) a	50.42 (21.449) a

Note. In parentheses = standard deviations. Significant difference with specific image version (at $p < .05$): a = original; b = grayscale; c = red; d = green. Valence, arousal and dominance are based on SAM scale; Skin conductance is presented after square-root transformation; Pupil size is presented in millimeters; Mean fixation duration–in seconds; Mean length of saccades and length of the whole scanpath are presented in degrees of visual angle.

participants felt significantly more in control while the original versions of images were presented compared to the red ($p < .001$, $d = 0.50$) or green ($p < .001$, $d = 0.45$) versions. The same was true when grayscale version was compared to red ($p = .008$, $d = 0.34$) and green ($p = .03$, $d = 0.29$). There were no other significant differences (see Table 3). The interaction between content and hue was not significant: $F(3, 60) = 1.428$, $MSE = 0.293$, $p = .244$, $\eta_p^2 = .067$, $1 - \beta = .36$ (see Table 4).

Comparison with IAPS norms. Since images were selected based on IAPS norms, current experimental stimuli evaluations were compared to equivalent IAPS norms (see Table 5). The Pearson correlations between them were significant in valence, $r = .664$, $N = 12$, $p = .018$, two-tailed and arousal, $r = .67$, $N = 12$, $p = .017$, two-tailed dimensions, while the correlation between dominance dimensions was not significant, $r = .273$, $N = 12$, $p = .391$, two-tailed.

Physiological Measures

Skin conductance. Analysis of skin conductance changes due to the presented picture revealed no significant main effect of content, $F(1, 20) = 0.368$, $MSE = 0.028$, $p = .551$, $\eta_p^2 = .018$, $1 - \beta = .09$, or hue, $F(3, 60) = 1.455$, $MSE = 0.051$, $p = .236$, $\eta_p^2 = .068$, $1 - \beta = .3$. The same was true for the interaction between content and hue: $F(3, 60) = 2.124$, $MSE = 0.098$, $p = .107$, $\eta_p^2 = .096$, $1 - \beta = .52$.

Pupil size. Pupil dilation analysis showed no significant main effect of content: $F(1, 20) = 3.825$, $MSE = 0.017$, $p = .065$, $\eta_p^2 = .161$, $1 - \beta = .46$ (see Table 2).

However, a significant main effect of hue was observed: $F(3, 60) = 43.597$, $MSE = 0.012$, $p = .001$, $\eta_p^2 = .686$, $1 - \beta = 1$. The largest pupil size was registered when grayscale versions of pictures were presented compared to original ($p < .001$, $d = 0.39$), red ($p < .001$, $d = 0.26$) or green ($p < .001$; $d = 0.49$) version. Slightly smaller sized pupils were evoked by the red version of images—it also significantly differed from original ($p = .04$, $d = 0.12$), grayscale ($p < .001$, $d = 0.26$) or green ($p < .001$; $d = 0.22$) version. There were no other significant differences (see Table 3).

Interaction between content and hue was also significant: $F(3, 60) = 2.788$, $MSE = 0.005$, $p = .048$, $\eta_p^2 = .122$, $1 - \beta = .64$. The largest pupil size was associated with the natural–grayscale combination compared to all other combinations (natural–original: $p < .001$, $d = 0.47$; natural–red: $p < .001$, $d = 0.30$; natural–green: $p < .001$, $d = 0.51$; urban–original: $p < .001$, $d = 0.45$; urban–grayscale: $p = .02$, $d = 0.14$; urban–red: $p < .001$, $d = 0.37$; urban–green: $p < .001$, $d = 0.61$). Other significant differences are presented in Table 4.

In order to take into account the possible covariation between pupil size and luminance—given that the potential effect of hue on luminance ($p = .052$, $\eta_p^2 = .174$), we carried out analysis of covariance (ANCOVA) with luminance as a covariate. ANCOVA did not change results: we obtained a main effect of hue, $F(3, 50) = 3.73$, $p = .02$, $\eta_p^2 = .27$, $1 - \beta = .75$, and an interaction between content and hue, $F(3, 50) = 2.84$, $p = .05$, $\eta_p^2 = .22$, $1 - \beta = .62$.

Behavioral Measures

Number of fixations. No significant main effect of content was found: $F(1, 20) = .195$, $MSE = 3.775$, $p = .664$, $\eta_p^2 = .01$, $1 - \beta = .07$ (see Table 2). However, there was a significant main effect of color: $F(3, 60) = 5.703$, $MSE = 2.851$, $p = .002$, $\eta_p^2 = .222$, $1 - \beta = .93$. Pairwise comparisons revealed that participants had a lower number of fixations on the green version than on original or grayscale ($p = .004$ and $p = .02$, respectively; $d = 0.30$ and $d = 0.26$, respectively) versions. There were no other significant differences (see Table 3). Interaction between content and color was not significant: $F(3, 60) = 1.237$, $MSE = 1.332$, $p = .304$, $\eta_p^2 = .058$, $1 - \beta = .31$ (see Table 4).

Mean fixation duration. A significant main effect of content was found: $F(1, 20) = 8.862$, $MSE = .004$, $p = .007$, $\eta_p^2 = .307$, $1 - \beta = .81$. Participants had a higher mean fixation duration on the natural pictures than on the urban pictures (see Table 2). There was also a significant main effect of color: $F(3, 60) = 5.655$, $MSE = .006$, $p = .002$, $\eta_p^2 = .22$, $1 - \beta = .93$. Pairwise comparisons revealed that the mean fixation duration while watching the original version of images was significantly lower compared to red and green versions ($p = .04$ and $p = .001$, respectively; $d = 0.56$ and $d = 0.71$, respectively). There were no other significant differences (see Table 3). However, there was no significant interaction between content and color: $F(1.645, 32.894) = 0.334$, $MSE = .008$, $p = .676$, $\eta_p^2 = .016$, $1 - \beta = .11$. (Mauchly's test indicated that the assumption of sphericity had been violated [chi-square = 32.714, $p = .001$]; therefore, degrees of freedom were corrected using Hyunh-Feldt estimates of sphericity [epsilon = .548]; see Table 4).

Mean length of saccades. A significant main effect of content was found: $F(1, 20) = 5.016$, $MSE = .375$, $p = .037$, $\eta_p^2 = .201$, $1 - \beta = .57$. Mean length of saccades was longer while viewing urban pictures compared to natural ones (see Table 2). Moreover,

Table 4
Mean Values of Valence, Arousal and Dominance Ratings, Skin Conductance Response, Pupil Size and Eye Movement Data for Different Content × Hue Version Combinations

Image contents		Valence	Arousal	Dominance	Skin conductance	Pupil size	Number of fixations	Mean fixation duration	Mean length of saccades	Length of the whole scanpath
Natural	Original (a)	6.237 (.753) b, c, d, f, g, h	4.138 (.944) c, e, f, g, h	5.784 (1.606) c, d, e, f, g, h	.589 (.296)	3.295 (.516) b, c, f, h	13.451 (4.543) d	.375 (.075) d	4.055 (.845) c	57.943 (19.939) d
	Grayscale (b)	4.762 (.939) a, e, h	3.881 (1.085) c, e, g, h	5.317 (1.451) c, g, h	.659 (.326)	3.551 (.559) a, c, d, e, f, g, h	13.267 (4.304) d	.417 (.108) e	3.748 (.815) e	51.448 (20.747) e
	Red (c)	4.27 (1.158) a, d, e	5.079 (1.298) a, b, f	4.786 (1.669) a, b	.8 (.467)	3.385 (.559) a, b, d, e, f, h	12.889 (3.709)	.432 (.148) e	3.595 (.902) a, e, g	52.556 (19.563) e
	Green (d)	4.956 (.860) a, c, e, h	4.481 (1.370) e, g	4.96 (1.598) a	.754 (.281)	3.277 (.519) b, c, f	12.147 (4.589) a, b, e, f	.44 (.129) a, e	3.769 (.836) e	48.11 (22.088) a, e, f
Urban	Original (e)	5.783 (.848) b, c, d, f, g, h	5.471 (1.334) a, b, d, f	5.087 (1.596) a, g, h	.706 (.353)	3.306 (.519) b, c, f, h	13.802 (4.198) d, g, h	.351 (.065) b, c, d, h	4.282 (1.145) b, c, d, h	64.026 (20.962) b, c, d, g, h
	Grayscale (f)	4.683 (.954) a, e, h	4.429 (1.209) c, e, g, h	5.024 (1.564) a, h	.703 (.420)	3.472 (.568) a, b, c, d, e, g, h	13.577 (3.929) d, g	.392 (.082)	3.948 (.974)	58.558 (18.373) d
	Red (g)	4.532 (.894) a, e	5.595 (1.343) a, b, d, f	4.524 (1.615) a, b, e	.588 (.324)	3.347 (.527) b, f, h	12.427 (3.959) e, f	.388 (.076)	4.026 (.829) c	53.021 (20.324) e
	Green (h)	4.135 (1.179) a, b, d, e, f	5.079 (1.384) a, b, f	4.492 (1.682) a, b, e, f	.742 (.425)	3.226 (.507) b, c, e, f, g	12.477 (4.502) e	.422 (.127) e	3.757 (1.013) e	52.73 (22.264) e

Note. In parentheses = standard deviations. Significant difference with specific combination of content and hue version (at $p < .05$): a = natural–original; b = natural–grayscale; c = natural–red; d = natural–green; e = urban–original; f = urban–grayscale; g = urban–red; h = urban–green. Valence, arousal and dominance are based on SAM scale; Skin conductance is presented after square-root transformation; Pupil size is presented in millimeters; Mean fixation duration–in seconds; Mean length of saccades and length of the whole scanpath are presented in degrees of visual angle.

a significant main effect of color was revealed: $F(3, 60) = 7.263$, $MSE = .196$, $p = .001$, $\eta_p^2 = .266$, $1 - \beta = .98$. Pairwise comparisons revealed that the mean saccade length while watching the original version of images was significantly greater than for any of the other versions (grayscale: $p = .008$, $d = 0.35$; red: $p = .002$, $d = 0.41$; and green: $p < .001$, $d = 0.44$). There were no other significant differences (see Table 3). However, there was no significant interaction between content and color: $F(2.299, 45.98) = 2.229$, $MSE = .202$, $p = .112$, $\eta_p^2 = .10$, $1 - \beta = .54$ (Mauchly's test indicated that the assumption of sphericity had been violated [chi-square = 11.82, $p = .038$]; therefore, degrees of freedom were corrected using Hyunh-Feldt estimates of sphericity [epsilon = .766]; see Table 4).

Length of the whole scanpath. No significant main effect of content was revealed: $F(1, 20) = 3.943$, $MSE = 222.448$, $p = .061$, $\eta_p^2 = .165$, $1 - \beta = .47$ (see Table 2).

However, there was a significant main effect of color: $F(3, 60) = 9.134$, $MSE = 94.295$, $p = .001$, $\eta_p^2 = .314$, $1 - \beta = .99$. Pairwise comparisons revealed that the length of the scanpath while watching the original version of images was significantly longer than watching all other versions (grayscale: $p = .03$, $d = 0.31$; red: $p = .002$, $d = 0.44$; green: $p < .001$, $d = 0.51$). There were no other statistically significant differences (see Table 3). No significant interaction between content and color was found: $F(3, 60) = 1.323$, $MSE = 67.675$, $p = .275$, $\eta_p^2 = .062$, $1 - \beta = .34$ (see Table 4).

Relations Between the Different Measures

In order to check for the possible relations of different measures, which were used in the experiment, Pearson correlations among mean values of valence, arousal and dominance ratings, skin conductance, pupil size and eye movement data were examined. One significant correlation between SAM scales was observed—a negative correlation between arousal and dominance ($r = -.9$, $N = 21$, $p = .001$, two-tailed). Additionally, there was a significant correlation between valence ratings and pupil size, $r = .497$, $N = 21$, $p = .001$, two-tailed. Lastly, there were some expected correlations between different eye movement data (see Table 6).

Discussion

The present study examined the emotional effects of content, hue, and their interaction. Based on the most prevalent hue-related associations, such as green–"calm", red–"threat", and gray–"boring" (Clarke & Costall, 2008; Elliot & Aarts, 2011; Kaya & Epps, 2004; Moller, Elliot, & Maier, 2009), it was hypothesized that green and grayscale versions of pictures would be the least arousing, while red and original would be the most arousing. Moreover, with respect to content, urban photographs were expected to be more arousing than natural images, given that natural surroundings have greater cognitive restorative ability compared to urban (Berman et al., 2008). Our results indicated that hue and content had emotional effects on self-reported, pupil size and eye movement/fixation data. As anticipated, their different combinations also affected the viewer in specific way.

Table 5
Comparison of Mean SAM Valence, Arousal and Dominance Ratings Between the Current Experiment Data and the IAPS Norms

	Valence		Arousal		Dominance	
IAPS No.	Experiment	IAPS	Experiment	IAPS	Experiment	IAPS
5040	6.8 (1.16)	5.39 (1.11)	5.05 (1.95)	3.75 (1.89)	5.75 (2.43)	5.77 (1.71)
5120	4.29 (1.62)	4.39 (1.34)	4.19 (1.89)	3.07 (2.12)	5.76 (2.10)	5.69 (2.07)
5532	5.14 (1.88)	5.19 (1.69)	4.24 (1.81)	3.79 (2.20)	5.86 (1.65)	6.01 (2.14)
5750	7.14 (1.20)	6.60 (1.84)	4.05 (2.18)	3.14 (2.25)	5.19 (1.91)	6.82 (2.25)
5780	7.9 (1.26)	7.52 (1.45)	2.57 (1.12)	3.75 (2.54)	6.33 (1.93)	6.05 (2.30)
5814	6.14 (2.03)	7.15 (1.54)	4.81 (2.46)	4.82 (2.40)	5.71 (2.33)	5.86 (2.05)
7242	6.19 (1.72)	5.28 (1.45)	5.29 (1.87)	3.83 (2.06)	5.24 (2.00)	5.72 (1.85)
7501	6.05 (1.77)	6.85 (1.70)	6.05 (1.91)	5.63 (2.27)	4.67 (2.11)	5.82 (2.07)
7510	5.67 (1.35)	6.05 (1.60)	5.24 (1.76)	4.52 (2.35)	4.38 (2.06)	4.96 (2.18)
7546	5.1 (2.15)	5.40 (1.13)	4.4 (1.90)	3.72 (2.16)	5.35 (1.76)	5.48 (2.0)
7650	5.81 (1.50)	6.62 (1.91)	5.71 (2.15)	6.15 (2.24)	5.43 (2.54)	5.79 (1.98)
9468	5.9 (2.14)	4.67 (1.80)	6.05 (1.83)	4.68 (1.89)	5.57 (1.94)	4.58 (2.09)

Note. In parentheses = standard deviations; IAPS = International Affective Picture System.

The Emotional Effects of Image Hue

First, the original versions of the pictures were rated as evoking the most positive emotions. Such findings are consistent with past research (Detenber et al., 2000) and may indicate that participants' valence ratings reflect participants' preference for "normal," non-manipulated stimuli, allowing a fluent processing of information (Reber, Schwarz, & Winkielman, 2004). Eye movement data supported this view. The mean length of saccades were greater on the original versions compared to the red, green and grayscale versions, suggesting more integrative visual processing through thorough binding of information (Henderson, 2011; Henderson & Hollingworth, 1999; Holmqvist et al., 2010) in the original photograph version. By contrast, mean fixation duration was higher for green and red color conditions. Increased mean fixation duration, according to the context, may be associated either with difficulties in encoding isolated objects or with the extraction of relations within complex scenes. Together with the observation that participants felt less in control (see below) when they viewed the red or green pictures than when they viewed the original pictures, the current pattern of results suggests that changing the color of the pictures induces a cost in visual search and tends to diminish its fluency.

We also observed an effect of hue on arousal. According to SAM ratings, grayscale pictures stood out as the least arousing. Because the grayscale hue has often been associated with "boredom" or "dullness" (Boyatzis & Varghese, 1994; Clarke & Costall, 2008; Kaya & Epps, 2004), this finding is coherent with existing literature. Several studies have also shown that higher saturation is associated with higher arousal (Gao & Xin, 2006; Ou et al., 2004; Valdez & Mehrabian, 1994), and grayscale images are distinguished by their low saturation value.

In the present study, pupil diameter was larger when viewing grayscale pictures compared to other photograph versions—even though preliminary analyses showed that there were no or limited differences of luminance between the different picture conditions. There was no evidence in this condition for any systematic association between self-reported arousal and pupil size. Therefore, pupil size may have varied with other factors than arousal (e.g., cognitive load associated with picture interpretation).

In contrast, no discrepancy between physiological responses and subjective experience of arousal was detected when red and green hues were compared. Red was hypothesized to be more arousing than green. Indeed, green hue has generally been considered more "calming" than red hue (Boyatzis & Varghese, 1994; Clarke & Costall, 2008; Kaya & Epps, 2004). This hypothesis was confirmed in the present study both by both arousal self-report and pupil data. Although effect size was relatively small, red versions of the images elicited larger pupil dilation compared to green ones.

Table 6
Correlation Between Valence, Arousal and Dominance Ratings, Skin Conductance Response, Pupil Size and Eye Movement Data

Variables	Valence	Arousal	Dominance	Skin conductance	Pupil size	Number of fixations	Mean fixation duration	Mean length of saccades	Length of the whole scanpath
Valence									
Arousal	−.130								
Dominance	.091	−.900*							
Skin conductance	−.054	−.083	.140						
Pupil size	.497*	.033	−.131	−.056					
Number of fixations	.126	.016	.005	−.191	.428				
Mean fixation duration	−.182	−.148	−.011	−.094	.011	−.479*			
Mean length of saccades	.271	−.022	.060	−.095	.169	.704*	−.546*		
Length of the whole scanpath	.366	.090	−.042	.007	.413	.795*	−.666*	.848*	

* Correlation is significant at $p < .05$.

In other words, the strength of the emotions elicited by the images was influenced by the color tint of the image. It is worth noting that in this study, the effect was observed using complex photographs, in contrast to most previous studies in which simple hue patches were used as stimuli.

Skin conductance and oculomotor behavior did not provide supplementary evidence concerning emotional arousal. We expected lower fixation number and scanpath length, and greater mean fixation duration on the less arousing hue (i.e., green and grayscale), in that emotional arousal tends to alter these oculomotor parameters (Bradley et al., 2011; El Sadek et al., 2013). Green and grayscale did not increase fixation duration and did not decrease fixation number and scanpath length, in comparison with the red version which was considered the most arousing hue. This may be imputable to the relatively low arousal of our picture set. The arousal difference between emotional and neutral pictures was higher in previous studies than the arousal difference between our green and red versions or our grayscale and red versions. As demonstrated by Tamir and Robinson (2007), highly arousing hedonic stimuli lead to preferential attentional processing compared to neutral stimuli, whereas lowly arousing hedonic stimuli and neutral stimuli are processed similarly. This can also explain the absence of statistical difference on skin conductance: previous studies used more arousing stimuli such as erotic or threatening pictures (Bernat et al., 2006; Bradley, Codispoti, Cuthbert, et al., 2001).

The Emotional Effects of Image Content

An effect of content on emotions was also observed. As predicted, natural contents were rated as more positive and less arousing than urban contents. Pupil size measures revealed that pupil diameter was bigger when viewing natural pictures compared to urban ones. This pattern of results was associated with an overall positive correlation between valence and pupil size—the more positive the valence, the bigger the pupil. This tends to support the idea that pupil size is not only associated with arousal (Bradley et al., 2011) but also with emotional valence—the more negative the valence, the smaller the pupil (Hess, 1972)—even when brightness is controlled for, as in our experiment. Moreover, recent research reported that when sad faces are presented with diminished pupil size (60% original area), the faces are judged as more negative than when pupil size is increased (167% original area; Harrison, Wilson, & Critchley, 2007). The sensitivity to pupil size may be the result of recurrent observations of covariation between emotional valence and pupil size in peers. Pupil size may then be influenced by both valence and arousal, through the mediation of hue in our experiment.

Eye movement data also partially supported our predictions about the different emotional effects of natural and urban contents. Urban scenes, considered the most arousing, led to longer saccades and lower fixation duration than natural scenes. The "urban search pattern" corresponds to an increased search rate, consistent with the findings of Bradley and colleagues (2011) and other eye movement data linking search rate to arousal (Janelle, 2002). There was no other effect of content on search "strategies" (i.e., number of fixations and the length of the whole scanpath). Moderate effect size and, as suggested above, the relatively small arousal differences between natural and urban contents can explain this matter of fact.

Interactions Between Hue and Image Content

An interaction between hue and content on valence self-report was observed. This interaction was particularly noticeable regarding the green version's valence. The green version was rated as evoking more positive emotions when associated with natural content than when associated with urban content.

Content and hue also interacted in arousal ratings. The original hue was rated as evoking less arousing emotions in pictures with natural content compared to pictures with urban content. The original version was the only photograph version where a significant difference between natural and urban contents was observed. Any influence of content could lack visibility in other hue versions, because global hue alteration (in comparison with the original version) could make hue the salient feature of visual scene perception (consistent with our previous discussion of the visual search cost in those conditions). The hypothesis that green–natural pictures are associated with the lowest arousal was not confirmed. This may result from the fact that combinations involving grayscale hue usually were the least arousing. Therefore, hue seems to be critical as far as arousal is concerned.

As regards to oculomotor data, the absence of interaction means that visual search is primarily influenced by hue and content rather than by their specific combinations. Hue and content could be processed in parallel in order to program visual search. This is consistent with previous research suggesting that eye movements are initiated as a function of multiple features that can be simultaneously processed (Findlay & Walker, 1999; Koch & Ullman, 1985).

Strengths and Limitations of Study

The present research revealed independent and interacting effects of hue and content on emotions. The main hypothesis of the study was therefore confirmed. In addition, by avoiding the use of simple hue patches and concentrating on more complex stimuli, the current study shows that the emotional effects of content can be altered by simply manipulating the color tint of a photograph—a manipulation which is frequent in the age of smart phones, monitors, and image editing software. However, our experiment sometimes had limited statistical power and effect size. It would be useful to conduct a similar study including slightly more arousing stimuli (e.g., snakes for natural and cars for urban content or blood for red hue). This would allow for more pronounced physiological responses (pupil size and skin conductance responses), which, in turn, would allow for a finer comparison of the effects of the image attributes of interest. In addition to the physiological variables used in the present study, which are usually associated with emotional arousal, it would be useful to include facial electromyography in order to strengthen the interpretation of valence (Bradley, Codispoti, Cuthbert et al., 2001; Lang & Bradley, 2010). This would also allow for a better and contextualized understanding of pupil data. This is important given the positive correlation between valence ratings and the pupil size observed in this study (and previous data suggesting that the pupil can reflect emotional valence; Lang & Bradley, 2010). Finally, the colors in this experiment were distinguished based on their hue. Manipulating brightness and saturation would help us understand how different image attributes interact within the same picture.

Conclusions

In the present study, the emotional responses associated with picture viewing were found to depend on (a) the picture hue, (b) the picture content, and (c) the Hue × Content interaction. Taken altogether, the results of this study suggest that the interaction between lower-level color perception and higher-level semantics should be further investigated, to better understand the coordination between physiological responses, cognitive experience, and behavior. Given the growing importance of virtual environments and color-modified visual displays (for instance on monitoring screens, electronic device that display artwork, or through the use of military spawns like night-vision goggles) that assist humans in critical tasks, it is important to gain knowledge about the interactions between the colors of the display and the semantics of the stimulation.

References

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science, 19,* 1207–1212. http://dx.doi.org/10.1111/j.1467-9280.2008.02225.x

Bernat, E., Patrick, C. J., Benning, S. D., & Tellegen, A. (2006). Effects of picture content and intensity on affective physiological response. *Psychophysiology, 43,* 93–103. http://dx.doi.org/10.1111/j.1469-8986.2006.00380.x

Bottomley, P. A., & Doyle, J. R. (2006). The interactive effects of colors and products on perceptions of brand logo appropriateness. *Marketing Theory, 6,* 63–83. http://dx.doi.org/10.1177/1470593106061263

Boyatzis, C. J., & Varghese, R. (1994). Children's emotional associations with colors. *The Journal of Genetic Psychology, 155,* 77–85. http://dx.doi.org/10.1080/00221325.1994.9914760

Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: Defensive and appetitive reactions in picture processing. *Emotion, 1,* 276–298.

Bradley, M. M., Codispoti, M., Sabatinelli, D., & Lang, P. J. (2001). Emotion and motivation II: Sex differences in picture processing. *Emotion, 1,* 300–319. http://dx.doi.org/10.1037/1528-3542.1.3.300

Bradley, M. M., Houbova, P., Miccoli, L., Costa, V. D., & Lang, P. J. (2011). Scan patterns when viewing natural scenes: Emotion, complexity, and repetition. *Psychophysiology, 48,* 1544–1553. http://dx.doi.org/10.1111/j.1469-8986.2011.01223.x

Bradley, M. M., Keil, A., & Lang, P. J. (2012). Orienting and emotional perception: Facilitation, attenuation, and interference. *Frontiers in Psychology, 3,* 493. http://dx.doi.org/10.3389/fpsyg.2012.00493

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25,* 49–59. http://dx.doi.org/10.1016/0005-7916(94)90063-9

Bradley, M. M., & Lang, P. J. (2007). The International Affective Picture System (IAPS) in the study of emotion and attention. In J. A. Coan & J. J. B. Allen (Eds.), *Handbook of emotion elicitation and assessment* (pp. 29–46). New York, NY: Oxford University Press.

Bradley, M. M., Miccoli, L., Escrig, M. A., & Lang, P. J. (2008). The pupil as a measure of emotional arousal and autonomic activation. *Psychophysiology, 45,* 602–607. http://dx.doi.org/10.1111/j.1469-8986.2008.00654.x

Burkitt, E., Barrett, M., & Davis, A. (2003). Children's colour choices for completing drawings of affectively characterised topics. *Journal of Child Psychology and Psychiatry, 44,* 445–455. http://dx.doi.org/10.1111/1469-7610.00134

Camgöz, N., Yener, C., & Güvenç, D. (2004). Effects of hue, saturation, and brightness: Pt. 2: Attention. *Color Research and Application, 29,* 20–28. http://dx.doi.org/10.1002/col.10214

Carniglia, E., Caputi, M., Manfredi, V., Zambarbieri, D., & Pessa, E. (2012). The influence of emotional picture thematic content on exploratory eye movements. *Journal of Eye Movement Research, 5,* 1–9.

Clarke, T., & Costall, A. (2008). The emotional connotations of color: A qualitative investigation. *Color Research and Application, 33,* 406–410. http://dx.doi.org/10.1002/col.20435

Detenber, B. H., Simons, R. F., & Reiss, J. E. (2000). The emotional significance of color in television presentations. *Media Psychology, 2,* 331–355. http://dx.doi.org/10.1207/S1532785XMEP0204_02

Detenber, B. H., & Winch, S. P. (2001). The impact of color on emotional responses to newspaper photographs. *Visual Communication Quarterly, 8,* 4–14. http://dx.doi.org/10.1080/15551390109363461

Elliot, A. J., & Aarts, H. (2011). Perception of the color red enhances the force and velocity of motor output. *Emotion, 11,* 445–449. http://dx.doi.org/10.1037/a0022599

El Sadek, M., Sayaka, S., Fujii, E., Koriesh, E., Moghazy, E., & Abd El Fatah, Y. (2013). Human emotional and psycho-physiological responses to plant color stimuli. *Journal of Food Agriculture and Environment, 11,* 1584–1591.

Findlay, J. M., & Walker, R. (1999). A model of saccade generation based on parallel processing and competitive inhibition. *Behavioral and Brain Sciences, 22,* 661–674. http://dx.doi.org/10.1017/S0140525X99002150

Frey, H. P., Honey, C., & König, P. (2008). What's color got to do with it? The influence of color on visual attention in different categories. *Journal of Vision, 8,* 6. http://dx.doi.org/10.1167/8.14.6

Frijda, N. H. (1986). *The emotions*. New York, NY: Cambridge University Press.

Gao, X. P., & Xin, J. H. (2006). Investigation of human's emotional responses on colors. *Color Research and Application, 31,* 411–417. http://dx.doi.org/10.1002/col.20246

Harrison, N. A., Wilson, C. E., & Critchley, H. D. (2007). Processing of observed pupil size modulates perception of sadness and predicts empathy. *Emotion, 7,* 724–729. http://dx.doi.org/10.1037/1528-3542.7.4.724

Henderson, J. M. (2011). Eye movements and scene perception. In S. P. Liversedge, I. D. Gilchrist, & S. Everling (Eds.), *The Oxford handbook of eye movements* (pp. 593–606). New York, NY: Oxford University Press.

Henderson, J. M., & Hollingworth, A. (1999). High-level scene perception. *Annual Review of Psychology, 50,* 243–271. http://dx.doi.org/10.1146/annurev.psych.50.1.243

Hess, E. H. (1972). Pupillometrics: A method of studying mental, emotional, and sensory processes. In N. S. Greenfield & R. A. Sternbach (Eds.), *Handbook of psychophysiology* (pp. 491–531). New York, NY: Holt, Rinehart & Winston.

Holmqvist, K., Nyström, M., Anderson, R., Dewhurst, R., Jarodzka, H., & van de Weijer, J. (2010). *Eye tracking: A comprehensive guide to methods and measures*. New York, NY: Oxford University Press.

Janelle, C. M. (2002). Anxiety, arousal and visual attention: A mechanistic account of performance variability. *Journal of Sports Sciences, 20,* 237–251. http://dx.doi.org/10.1080/026404102317284790

Kaya, N., & Epps, H. H. (2004). Relationship between color and emotion: A study of college students. *College Student Journal, 38,* 396–405.

Koch, C., & Ullman, S. (1985). Shifts in selective visual attention: Towards the underlying neural circuitry. *Human Neurobiology, 4,* 219–227.

Lang, P. J., & Bradley, M. M. (2010). Emotion and the motivational brain. *Biological Psychology, 84,* 437–450. http://dx.doi.org/10.1016/j.biopsycho.2009.10.007

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual* (Technical Report A-8). Gainesville, FL: University of Florida.

Lapė, J., & Masiliūnaitė, L. (2001). Spalvos įtaka reklamos poveikiui. *Psichologija, 23,* 79–87.

McKelvie, S. J., Sano, E. K., & Stout, D. (1994). Effects of colored separate and interactive pictures on cued recall. *The Journal of General Psychology, 121,* 241–251. http://dx.doi.org/10.1080/00221309.1994.9921199

Moller, A. C., Elliot, A. J., & Maier, M. A. (2009). Basic hue-meaning associations. *Emotion, 9,* 898–902. http://dx.doi.org/10.1037/a0017811

Niu, Y., Todd, R. M., & Anderson, A. K. (2012). Affective salience can reverse the effects of stimulus-driven salience on eye movements in complex scenes. *Frontiers in Psychology, 3,* 336. http://dx.doi.org/10.3389/fpsyg.2012.00336

Nummenmaa, L., Hyönä, J., & Calvo, M. G. (2006). Eye movement assessment of selective attentional capture by emotional pictures. *Emotion, 6,* 257–268. http://dx.doi.org/10.1037/1528-3542.6.2.257

Ou, L., Luo, M. R., Woodcock, A., & Wright, A. (2004). A study of color emotion and color preference, part II: Color emotions for two-color combinations. *Color Research and Application, 29,* 292–298. http://dx.doi.org/10.1002/col.20024

Pilarczyk, J., & Kuniecki, M. (2014). Emotional content of an image attracts attention more than visually salient features in various signal-to-noise ratio conditions. *Journal of Vision, 14,* 4. http://dx.doi.org/10.1167/14.12.4

Polzella, D. J., Hammar, S. H., & Hinkle, C. W. (2005). The effects of color on viewers' ratings of paintings. *Empirical Studies of the Arts, 23,* 153–163. http://dx.doi.org/10.2190/ECK9-C18E-RQN9-7WNE

Reber, R., Schwarz, N., & Winkielman, P. (2004). Processing fluency and aesthetic pleasure: Is beauty in the perceiver's processing experience? *Personality and Social Psychology Review, 8,* 364–382. http://dx.doi.org/10.1207/s15327957pspr0804_3

Rousselet, G. A., Joubert, O. R., & Fabre-Thorpe, M. (2005). How long to get to the "gist" of real-world natural scenes? *Visual Cognition, 12,* 852–877. http://dx.doi.org/10.1080/13506280444000553

Sander, D., & Scherer, K. R. (2009). La psychologie des émotions: Survol des théories et débats essentiels [Psychology of emotions: Overview of theories and essential debates]. In D. Sander & K. R. Scherer (Eds.), *Traité de psychologie des émotions* [Treatise on psychology of emotions] (pp. 1–39). Paris, France: Dunod.

Spence, I., Wong, P., Rusan, M., & Rastegar, N. (2006). How color enhances visual memory for natural scenes. *Psychological Science, 17,* 1–6. http://dx.doi.org/10.1111/j.1467-9280.2005.01656.x

Tamir, M., & Robinson, M. D. (2007). The happy spotlight: Positive mood and selective attention to rewarding information. *Personality and Social Psychology Bulletin, 33,* 1124–1136. http://dx.doi.org/10.1177/0146167207301030

Terwogt, M. M., & Hoeksma, J. B. (1995). Colors and emotions: Preferences and combinations. *The Journal of General Psychology, 122,* 5–17. http://dx.doi.org/10.1080/00221309.1995.9921217

Valdez, P., & Mehrabian, A. (1994). Effects of color on emotions. *Journal of Experimental Psychology: General, 123,* 394–409. http://dx.doi.org/10.1037/0096-3445.123.4.394

van den Berg, A. E., Koole, S. L., & van der Wulp, N. Y. (2003). Environmental preference and restoration: (How) are they related? *Journal of Environmental Psychology, 23,* 135–146. http://dx.doi.org/10.1016/S0272-4944(02)00111-1

Walsh, L. M., Toma, R. B., Tuveson, R. V., & Sondhi, L. (1990). Color preference and food choice among children. *The Journal of Psychology: Interdisciplinary and Applied, 124,* 645–653. http://dx.doi.org/10.1080/00223980.1990.10543258

Zentner, M. R. (2001). Preferences for colours and colour-emotion combinations in early childhood. *Developmental Science, 4,* 389–398. http://dx.doi.org/10.1111/1467-7687.00180

Zettl, H. (2005). *Sight, sound, motion* (4th ed.). Belmont, CA: Thomson Wadsworth.

Received June 21, 2014
Revision received July 7, 2015
Accepted September 10, 2015 ■