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Color-Emotion Mappings and their Demographic Dependencies in Digital Environment: Online Test Evidence Using MS Paint 7 Color Palette

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Abstract. With some overlapping and contradicting results a number of studies have demonstrated that there is an interrelation between colors and emotions. Some studies conclude that colors and other aesthetic effects are strong emotion triggers inducing affective reaction when interacting with interfaces or webpages. Our study tests color-emotion mappings in interface environments within a modified framework of Ou et al. (2004a, b, c) applying a rating task in an in-group quasi-experimental setting for colors selected from a typical color scheme (MS Paint 7 Palette) used in digital environments. We have characterized and grouped the tested colors with respect to evaluation tendencies regarding emotion association pairs - polar adjectives used in the rating task. Correlations between colors that are evaluated similarly with respect to emotion association pairs as well as emotion association pairs evaluated similarly with respect to the tested colors have also been detected and discussed in the study. The study contributes to the interrelated areas of interface usability and design analysis, usability improvement, and interface color categorization. The results show that perception of color-emotion mappings is age and gender dependent.

Keywords: colors, emotions, interfaces, demographic factors

Introduction

Colors and other aesthetic effects (e.g., expressed in figural shapes) are strong emotion triggers that induce affective reactions arising early and are relatively persistent in interface or webpage evaluation (Tractinsky et al., 2000). Furthermore, colors are shown to contribute to the overall aesthetic impact and attractiveness of the interface on the user (Bonnardel et al., 2011; Hassenzahl, 2004; Tractinsky et al., 2000, Brom et al., 2018).

Sensitivity to colors within the framework of our study arises from two interrelated groups of factors: (a) colors mediate or induce emotions (Ou et al., 2004a,b,c) (b) color categorization is related to general world and object knowledge (Palmer et al., 2016; Schloss and Palmer, 2017). Converging the results from both groups it can be further hypothesized that colors mediate emotions that are in turn at least partially linked to the world-knowledge including concrete physical spatially extended objects possessing typical object color or temporal objects such as events, abstract concepts (e.g. ‘freedom’), and heterogeneous knowledge about social institutions (in case of interfaces - financial, medical, or educational institutions).

A general principle underlying interface use is the idea that the first impression is generated by aesthetic, design and emotional factors and colors play a crucial role in this stage of interaction. Even if not functionally perfect, a visually appealing interface or webpage is preferred over a functionally perfect but visually less appealing one (Hartson and Pyla, 2012) because usability preferences arise at a later stage (Bonnardel et al., 2011).

Usage context (webpage type (e.g., financial, medical, or commercial) and content) constrains the choice of colors that users prefer for a particular interface (Zariņa et al., 2019). Color schemes appropriate for, e.g., educational interfaces, might not be appropriate for an entertainment interface type.

In virtue of induced emotional reactions, there are disagreeable and agreeable colors and figural elements that should be avoided or, in contrary, recommended when designing an interface system. Although color preferences are constrained by the task of the webpage (Zariņa et al., 2019), we would like to provide an empirically supported overview of color selection from MS Paint 7 Palette (adapted for and frequently used in interface contexts) as to how agreeable or disagreeable they are depending on the demographic profile of the user.

Further, we will provide an overview of the research on color and emotion mappings (1.1.), explain how color and emotion mappings contribute to the research on interface perception (1.2.), provide the background of our study (1.3.), describe research design and methods (2.). Finally, following the analysis of the experimental results (3.), discussion of the results and conclusions will be offered (4.)

1. Theoretical Background

1.1. Color and emotion mappings

The idea that colors and emotions are mapped together depending on the age and other factors is prominent in cognitive science (Hanada, 2018; Josserand et al., 2021; Jonauskaite et al., 2020; Taylor et al., 2013; Terwogt and Hoeksma, 1995; Valdez and Mehrabian, 1994). Prior to analyzing differences in research frameworks on color-emotion mappings, a brief description of the essence of what is meant by emotion in the current study will be given.

Emotions are usually defined as one type of an affective state (Scherer, 2005). Although there are interrelations, emotions have to be distinguished from preferences (relatively stable evaluative conditions), attitudes (“relatively enduring beliefs and predispositions towards specific objects or persons” (Scherer, 2005, p. 703)), moods (rather diffuse affect states frequently occur without a causal link to an event; last hours or days), affective dispositions (personality traits, behavior tendencies towards certain mood or emotion), and interpersonal stances (affective styles in interaction with individuals or groups) (Scherer, 2005).

Emotions are (a) event focused (i.e., they are elicited by stimulus events), (b) appraisal driven (events and consequences are evaluated as more or less relevant to major concerns of the organism; emotions provide organism with evaluatively adaptational functions), (c) rapidly changing according to events (changes in environment, re-evaluation of events), (d) with high intensity (e.g., higher than just moods), (e) short in duration (to enable behavioral flexibility) (Scherer, 2005). Although in everyday situations emotions can and do overlap with other affective states (e.g., sad mood would typically induce sad or negatively valenced emotions; people with different affective dispositions might react differently to the same event), the distinct emotional component of human experience is characterised by event-focus (e.g., moods are not necessarily linked to an event), intensity (other affective states are typically less intensive), speed (emotions are faster than other affective states), and durability (emotions are adaptively linked to concrete events or concrete stimuli and therefore shorter than other affective states).

In the research concerning emotions, there are several frameworks that overlap but are also divergent in several aspects. First, there are theories assuming that a small number of basic emotions (such as anger, fear, happiness) are discrete, modular (e.g., Ekman, 1992a, b, for a recent critical review cp. Ortony, 2022). Second, there is an approach arguing for dimensionality of all emotional experience; all emotions vary at least according to the degree of valence (positive / negative) and activity (Russell, 1980; Russell and Barrett, 1999). Third, it is also possible that emotions are experienced in clusters (e.g., a variety of happiness emotions might be clustered with joy while anxiety, fear, and horror are eventually clustered together) (e.g., Cowen et al., 2019; Cowen and Keltner, 2021). Despite the differences between these groups of theories, there is a common although sometimes implicitly shared underlying principle that emotions have some dimensional structure both in case of basic emotions (which can be structured according to valence and activity) and also emotion clusters (which contain some dimensional structure as well). Therefore, the dimensional approach to emotions can be seen as somewhat unifying. Jackson et al. (2019) provide some evidence supporting the relative cross-cultural universality of valence and activity dimension.

The research on color-emotion mappings has been conducted from a variety of perspectives and some studies have a more theory-driven framework (such as Ecological Valence Theory (Schloss and Palmer, 2015)) whereas others are primarily data-driven (e.g., Volkova et al., 2012).

The present research uses several frameworks on color categorization and interrelations with emotions. Ou et al. (2004a, b, c) offer a detailed framework where Semantic Differential-like adjective pairs (emotionally loaded association words) are used to evaluate colors. According to traditional Semantic Differential studies (Adams and Osgood, 1973; Madden et al., 2000), some colors seem to be cross-culturally affectively salient (e.g., black and grey - bad but white, blue, and green - good; black and grey - passive but red – active).

The Ou et al. (2004a,b,c) approach is distinct in its use of emotionally shaped associations (ordered according to pleasure, arousal, and dominance dimensions) instead of relatively pure emotion measurement scales which are used either in the frameworks of discrete emotions (Ekman, 1992a,b; Izard, 1991; Plutchik, 1980) or dimensional emotion measurements (Russell, 1980; Russell and Barrett, 1999). However, it has some advantages such as intuitive meaning and relevance with respect to interface systems, sensitivity of measurements (which has been tested in previous studies, see Valdez and Mehrabian (1994)); at the same time the sets of scales are linked to canonical and experimentally supported dimensions of emotion measurement (pleasure and arousal).

The scales facilitate exploration of some cross-modal links. This is further discussed in the sections about stimuli.

A crucial study by Valdez and Mehrabian (1994) (for a critical discussion see also Simmons (2015)) used Munsell color system to test pleasure-arousal-dominance model of emotion (see this study also for a comprehensive overview on color-emotion mapping research until 1994). This model was derived from Osgood et al. (1957) where pleasure-displeasure was constructed as a counterpart of evaluation, arousal-non-arousal activity, and dominance-submissiveness as the correlate of potency. According to this study, saturation and brightness have strong effects on emotions (hue, however, was less important). The most pleasant hues according to Valdez and Mehrabian (1994) were blue, blue-green, green, red-purple, purple, and purple-blue while the least pleasant were yellow and green-yellow. Most emotionally arousing were green-yellow, blue-green, and green but least exciting - purple-blue, yellow-red. Green-yellow were graded as the most dominant. David Simmons (2015) tested an extensive set of colors in Munsell system with respect to such emotional terms as ‘pleasant’, ‘unpleasant’, ‘mood-enhancing’ and ‘calming’ and also observed some reliable color-emotion mappings.

Color emotion mappings can also be explained with regards to the impact of object knowledge - the core assumption of the Ecological Valence Theory (Schloss and Palmer, 2015). According to this approach, “people like/dislike colors to the degree they like/dislike the objects that are characteristically associated with that color.” (Kaya and Epps, 2004; Strauss et al., 2013; Taylor et al., 2013). Differences in object/event knowledge is reflected in different color preferences (Schloss and Palmer, 2017) and can be seen as a possible source of affective reaction to colors (besides physiological and cultural factors).

The Ecological Valence Theory is at least partially consistent with the recent cross-cultural study by Gibson et al. (2017) confirming the color-usefulness hypothesis according to which “differences in color categorization between languages are caused by differences in overall usefulness of color to a culture.” Contrary to the principle of perceptual salience it seems that humans use certain colors more frequently because these colors support communicative needs, i.e., the objects that people talk about more frequently are warm-colored whereas backgrounds are cool-colored (Gibson et al., 2017) (more on warm and cool colors see Holmes and Regier (2016)). Cultures vary in terms of how useful a color is although there is evidence that the pattern may be universally applicable. According to Gibson et al. (2017), warm colors (yellow/red) assuming the role of figure objects are preferred over cold colors (blue/green) which are used for the background. This, however, does not agree with some of the research on color in consumer psychology (Babin et al., 2003). In general, Gibson et al. (2017) provide an alternative to the idea of relative color universality (Berlin and Kay, 1969; Lindsey and Brown, 2006; Regier et al., 2007) and color relativity (Roberson et al., 2005; Roberson and Hanley, 2007).

Support for color and emotion mappings and its representation in language also derives from computational work (Volkova at al., 2012) who argue there is a consistent link between colors and concepts, on one hand, and colors and emotions, on the other hand. Computational emotion extraction from large-scale databases provides further support for the idea of emotion and color mappings (Csurka et al., 2010) as well as emotion and concept (Jahanian et al., 2017) mappings.

If explored in more detail, color-emotion mappings are highly age dependent (Boyatzis and Varghese, 1994; Ou et al., 2011; Terwogt and Hoeksma, 1995): not only adult and children color-emotion mappings are very different, children’s emotional associations with colors are also crucially different at different ages. Although children seem to generally assign positive reactions to bright colors and negative to dark colors, emotional relations to particular colors are relatively distinct and there are systematic gender differences in emotional reactions to different colors (Boyatzis and Varghese, 1994).

Color and emotion correlation also supports the idea of general atmospherics of the environment. For instance, colors seem to support decision-making and are a significant factor in the analysis of shopping intentions (Babin et al., 2003). According to the results by Babin et al. (2003), in fashion stores blue interiors enhance buying intentions if compared to the orange color which does not (these results have to be considered with some caution because the sample consisted of more than 200 females from university which is a rather specific user segment). A link between colors and performance attainment is also confirmed by Elliot et al. (Elliot et al., 2007) who argue that even a very brief viewing of red might impact motivation - the red color before an achievement task impairs performance even if the subjects are not aware of the effect. This is crucially important when generating or improving color schemes for e-commerce, in general, and internet store platforms, in particular.

Similar findings supporting the idea that consumers' decisions are sensitive to product colors has been explored in a comprehensive qualitative study by Kauppinen-Räisänen and Luomala (2010). Packaging colors not only attract attention but also create aesthetic experience shaping the decisions. Furthermore, the type of the product also shapes color meanings. These results have direct relevance when improving interface design of internet stores.

Atmospherics as a factor impacting decision in commercial contexts is relatively understudied. However, some evidence from physical stores (Spence et al., 2014) indicates that the commercial environment shapes customer experience. In our study we are tentatively assuming that commercial interface environments are emotionally somewhat similarly shaped as are physical environments. Also, the results by Spence and colleagues (Spence et al., 2014) show that affective factors linked to colors (and other sensory modalities) substantially shape the customer experience and shopping behavior. We agree with Spence et al. that "visual cues may trigger specific associations in consumers that can facilitate decision making. Studies suggest that changing the visual atmospherics, whether in terms of the overall brightness and hue of the lighting or the in-store color scheme influences purchase intentions and sales" (Spence et al., 2014).

Still another fascinating area of color categorization is the structure of relations between colors and other modalities (e.g., touch, smell, haptics) or modality relatively unrelated information (e.g., temporal). Links between time perception and colors in interface systems (Gorn et al., 2004) are discussed in the discussion part of this article. Another interesting mapping is the one between color and weight (Alexander and Shansky, 1976) demonstrating that darker colors are categorized as heavier - red is perceived as the heaviest while yellow as the lightest (see a pioneering work by Bullough (1907); for a discussion see Strauss et al., (2013)). According to a recent work by Barilari et al. (2018), red is seen as heavier than yellow even in non-sighted population (although to a lesser extent) which means that cross-modal links are not only due to perceptual experience but also due to non-perceptual color knowledge (e.g. from linguistically represented knowledge). Although we will not focus on cross-modal links (Spence, 2011), we will present some scales (e.g., Light-Heavy) that are included in emotion-association scales (Light-Heavy as a part of dominance / potency scale-set, see Table 2) and are also cross-modally interesting.

1.2. Colors and emotions in interface analysis

Humans are sensitive to colors and emotions. Hence interface environments is another dimension of complexity where both are interrelated. This is an especially important area because emotions guide action: emotions and affects are “powerful, commanding attention and altering agendas for thought and action.” (Clore and Ortony, 2013).

In a more detail, colors (mediated by emotions) can be factors determining trust towards particular websites and e-services (Conway et al., 2010; Pelet and Papadopoulou, 2013; Pelet et al., 2013). Colors as emotion-triggers and mediators can help customers overcome fear and uncertainty and generate feeling of trust. By experimentally manipulating hue, saturation, and brightness, Pelet and colleagues (Pelet et al., 2013) were able to observe impacts of contrast, foreground brightness and foreground saturation on the effects of arousal which (together with pleasure and dominance) impacts trust. Therefore, emotional arousal in the use of websites is a significant factor in developing trust. Pelet and colleagues (Pelet et al., 2013) further argue that familiarity, clarity of interface and transparency of information also support positive atmospherics of the site.

An additional set of factors constraining color-emotion mapping is the availability of operational perceptual and cognitive resources (Meyers-Levy and Peracchio, 1995): when processing motivation is low, only few resources are available, whereas with high motivation users engage in more effortful processing. According to the results by Meyers-Levy and Peracchio (1995) after testing the affective reaction to ad colors: black-white seems to be more relevant (less distracting) when processing requires more resources (even when users are motivated). Involving more colors improves performance as in cases when users invest less resources (e.g., lack motivation).

Finally, impact of positive emotions on the use of interface systems might be also considered in a wider context: according to the Broaden-And-Build theory of positive emotions (Fredrickson, 2004), positive emotions support and broaden individual action (e.g., interest supports motivation to explore, contentment supports intention to integrate and savor) and promote creative actions and ideas that accumulate individual’s cognitive resources in physical, social, and intellectual sense. Therefore, interfaces that induce positive emotions might have a more complex positive response exceeding the situation of interaction with the interface system. Recent research also points to the applicability of color-emotion links in user interface design for autism research (Ismail et al., 2021), museum management systems (Kim and Lee, 2022), situation-aware user behaviour (Herdin and Märtin, 2022) to mention just a few.

1.3. Our study

In the current study we explore color-emotion mappings and their dependency on different demographic profiles (including such factors as age, gender, education level and education field etc. (Section 2.1.)) in interfaces. We assume that interface users not only prefer certain colors but also map them inherently and automatically onto emotions. Mapping colors onto emotions is not only a culture specific process but also dependent on age and other demographic variables.

We adopt a modified framework of color-emotion preferences that was elaborated by Li-Chen Ou et al. (2004a, b, c). According to their study, “feelings, evoked by either colors or color combinations, are called color emotions” (Ou et al., 2004a) - e.g. excitement, energy, or calmness.

According to Ou et al. (2004a, b, c), there seem to be a relatively strong and universal preferences for the factors of color activity, color weight, and color heat resulting in sensitive (although to some extent culture-dependent) pairs of color emotions or emotion associations (since they refer to typical connotative meanings that are emotionally valenced) such as Warm-Cool, Light-Heavy, Active-Passive, and Soft-Hard. Color emotions seem to have a variety of underlying factors such as happiness, forcefulness, dynamism etc. (Ou et al., 2011). When explored in a more detail, the following groupings of factors seem to arise: (a) hue-related emotionally associative factors (warmth, coolness, heat, temperature), (b) lightness-related emotionally associative factors (light/heavy, soft/hard, potency), and (c) chroma-related emotionally associative factors (active/passive, dynamism, impact) (Ou et al., 2011; Ou et al., 2018). In our study we are manipulating hues according to some typical (in our case, MS Paint 7 color palette) build-in colors (since the task occurs in everyday digital environments using different devices and different light conditions). The rationale behind the use of MS Paint 7 is a default color palette adapted for interface use in controlling irritation that might cause visual fatigue or distraction in user (e.g., brightness is reduced) (Hartson and Pyla, 2012, 797).

Traditionally, color-emotion mappings can be explored either by applying scales (typically similar to semantic differential) or using categorical judgements. Results from both methods seem to be correlated (Ou et al., 2012; Ou et al., 2018). In our study we are applying a scale-based approach similar to Ou et al. (2004a, b) However, there are also some important differences with respect to Ou et al. (2004a, b). First, we use online quasi-experimental instead of a laboratory setting, thus providing a better ecological validity. Second, we use 5-point scale instead of forced-choice task where subjects have to choose among two color alternatives. Third, we have added some additional rating scales (see 2.2. Stimuli section below). Some of the scales used in our study are consistent or overlap with the seminal study by Kobayashi (1981) on mapping between color images and semantic differential type of attribute pairs (e.g., feminine/masculine). We do not systematically vary lightness and saturation and therefore do not apply Kobayashi's attributes that in his approach refer to every color and generate the Color Image Scale: warm/cool, soft/hard, and clear/grayish.

At the same time, we are aware and agree with the methodological issues of color-emotion measurements (Valdez and Mehrabian, 1994) that a frequent problem concerns insufficiencies in defining independent (e.g., quality of stimuli) or dependent (quality of measures or scale construction) variables. However, when testing interfaces in real-life environments some imprecision in independent variables should be taken into account (but at the same time controlled in terms of the overall pattern of results with respect to the selected stimuli set). In our analysis, we cannot include the factors of saturation and brightness since this would require conducting a laboratory experiment. However, the advantage of our study lies in the ecological validity of the task which is rarely present in laboratory studies on color categorization.

A final note on terminology and experimental structure of the current study: in our study we are using emotionally distinguished pairs of adjectives ('color emotions' as labeled by Ou et al., 2004a) referring to different emotions. The rationale is that we are operationalizing emotions by instantiating them into emotionally associative (distinguished according to a particular valence) adjective pairs on a set of scales (Adams and Osgood, 1973; Osgood et al., 1957; for recent applications see, e.g., Ding and Bai, 2019, Kuo et al., 2022, Spence, 2020); the scales are based on Semantic Differential method and ordered according to the dimensions of pleasure (linked with evaluation; the scales: Clean-Dirty, Fresh-Stale, Like-Dislike), arousal (linked with activity; scales:

Warm-Cool, Modern-Classical, Active-Passive, Relaxed-Tense), and dominance (linked with potency in classical Semantic Differential set of variables; scales: Warm-Cool, Modern-Classical, Active-Passive, Relaxed-Tense). This approach has been tested in numerous studies (most notably by Valdez and Mehrabian (1994)) and widely used by Ou et al. (2004a,b,c) and is more intuitive when colors have to be rated. Finally, a study by Cavanaugh et al. (2016) shows clear converging evidence for mappings between 29 perceptual dimensions (e.g., brightness, taste, speed, temperature) and emotions and concludes that perceptual dimensions differentiate emotions.

2. Methods

2.1. Participants

In total 304 subjects participated in the study. The vast majority (91%) are participants of Latvian nationality. Only 23% of participants in our sample are male, which consequently has to be taken into account when interpreting the results. Participants are relatively uniformly distributed across the age groups: 25% under 26 years, 26% from 26 to 35 years, 23% from 36 to 45 years, 17% from 46 to 55 and 9% above 55 years. About 60% of respondents have at least a bachelor's degree. Also, our sample contains people from different science backgrounds - social sciences (22%), humanities (24%), natural sciences (9%), engineering (11%), etc. and also people from different places of residence - the capital city (42%), other major cities (39%), the country area (19%). The demographic information also includes a question about deficits in color vision.

2.2. Stimuli and setup

This study uses the color-emotion rating task adapted from Ou et al. (2004a, b, c) - for pilot results see Šķilters et al. (2018b). We selected some basic colors, simple and clear, aiming to avoid large differences depending on various displays or devices and different projection circumstances. The chosen colors conform with the MS Office 2010 standard palette (MS Paint 7 Palette, the basic colors that are adapted for use in a digital environment) (Table 1).

Table 1. Color stimuli used in the study

Color	Red (R)**	Orange (O)**	Yellow (Y)**	Green (G)**	Blue (B)**
HTML code	#ED1B24	#FF7F26	#FEF200	#23B14D	#00A3E8
Color	Purple (P)**	Pink (Pi)**	Brown (Br)**	White (W)**	Black (Bl)**
HTML code	#A349A3	#FEAEC9	#B97A57	#FFFFFF	#000000
(**) Henceforth these abbreviations will stand for color descriptions in tables and figures					

The polar adjectives used in rating task (Table 2) were modified from Ou et al. (2004a, b, c), who have based their approach on Semantic Differential-style antonym structure (Adams and Osgood, 1973; Osgood et al., 1957; Hogg, 1969; Madden et al., 2000).

Table 2. Polar adjectives used in the scales of the rating task

Pleasure - displeasure as the correlate of evaluation (*)		**Arousal - non-arousal as the correlate of activity (*)**		**Dominance - submissiveness as the correlate of potency (*)**		**Added pairs for color categorization in interface systems**	
Clean-Dirty	Cln-Drt**	Warm-Cool	Wrm-Cl**	Light-Heavy	Lgt-Hv**	Safe-Unsafe	Sf-Usf**
Fresh-Stale	Ft-Stl**	Modern-Classical	Mdn-Cls**	Soft-Hard	Sft-Hrd**	Harmonious-Disharmonious	Hm-Dhm**
Like-Dislike	Lk-Dlk**	Active-Passive	Act-Ps**	Feminine-Masculine	Fm-Msc**		
		Relaxed-Tense	Rlx-Tns**				

(*) from Ou et al. (2004a, b, c); Valdez and Mehrabian (1994).
(**) Henceforth these abbreviations will stand for adjectives in tables and figures

We used a scale's evaluation structure defined and tested in the study by Valdez and Mehrabian (1994) according to the assumption that pleasure-displeasure was considered as the correlate of evaluation (corresponding scales: Clean-Dirty, Fresh-Stale, Like-Dislike), arousal and non-arousal as the correlate of activity (scales: Warm-Cool, Modern-Classical, Active-Passive, Relaxed-Tense), and dominance-submissiveness as the correlate of potency (scales: Light-Heavy, Soft-Hard, Feminine-Masculine) (Table 2). We have added two emotion association pairs - Safe-Unsafe and Harmonious-Disharmonious as these might provide some important information about color categorization in interface systems (e.g., perceived safety might be an important attribute in financial transaction systems) and the sense of harmony might be a proxy for aesthetic preferences. We assume that both safety and harmony scales are somewhat intuitive and polysemous and assume they have relatively clear emotional profiles. In contrast to other approaches (e.g., Ou et al., 2012; Ou et al., 2018), we have not considered two color combinations rating harmony. Instead, we assumed an intuitive fit between colors and the corresponding perceived emotional valence and activation, aesthetical impact, as a part of ceteris paribus contexts (for a comprehensive discussion see Kuehni (2005), e.g., p. 161).

The scales used by Ou et al. (2004a, b, c) have been criticized (Simmons, 2015) for not using direct emotion trigger-words but measuring emotion associations only. However, these stimuli have some crucial advantages for the purpose of our study: (a) as associative proxies to emotions they provide valuable information when interface color schemes are improved or transformed and, thus, have more ecological validity with respect to the variety of everyday tasks (interaction with interfaces including): emotion-association scales if expressed in a Semantic Differential scale sets (see Table 2) are more intuitive and are still preserving valence and activation structure (additionally also the dimension of dominance), (b) they include some antonyms that might enable analysis of cross-modal links between colors attributed from other perceptual domains (e.g., Light-Heavy, Soft-Hard, Warm-Cool).

Each color and adjective opposition on a 5-point scale was displayed separately in a randomized order.

2.3. Task design and procedure

A compound in-group design quasi-experiment with three different online sub-tasks was conducted including 144 questions in total: (1) color-emotion mappings (n=120), (2) a filler task (visual search task) (n=3), and (3) color combinations (n=10). The questionnaire was concluded by a set of demographic questions (n=11). In the current study, we focus on the results of the first task.

After an instruction the subjects were asked to rate colors in a 5-point scale according to the adjective oppositions representing emotion associations (adapted from Ou et al. (2004a, b, c), modified from Hogg (1969) and Osgood et al. (1957)). First, participants were introduced with an example task where 'grey' was presented and asked to respond to the question "Please, rate the color" according to the 5-point scale referring to the adjective opposition 'Bright-Pale'. In the example, the adjective opposition rating scale was described as follows: 1 - bright, 2 - rather bright, 3 - hard to tell, 4 - rather pale, 5 - pale. Further, experimental stimuli were presented in a random order, requiring to answer the same question "Please, rate the color" regarding different pairs of adjective oppositions (e.g., Light-Heavy, Soft-Hard, Warm-Cool) without description of the middle part of the scale. After completing the experimental part, the subjects were asked to answer an extended set of demographic questions.

The questionnaire was created and distributed as a link together with an instruction using QuestionProTM tool. The median time for filling in the surveys was 20 minutes.

Among the differences in this study compared to Ou et.al. (2004a, b, c), two have to be discussed in a more detail. First, in contrast to Ou et al. (2004a, b, c), in our study participants were not given the definitions of color emotions before the study. (Ou et al. (2004a, b, c) used definitions adapted from Cambridge Advanced Learner's dictionary.) The meaning of the color terms for native (or close-to-native) speakers of Latvian seems to be unambiguous and uncontroversial. Additionally, the definitions would increase the task time. Second, regarding the first survey, in contrast to Ou et al. (2004a, b, c), the subjects were asked to rate colors according to 5-point emotion association scale (instead of selecting one of two oppositions in color emotion associations).

2.4. Statistical methods

Color-emotion mappings were summarized using boxplots for each color-emotion pair. This allows for visual inspection as well as to evaluate the degree of relatedness between each color and emotion association. An overview of the distribution of answers is more appropriate for this type of data. Reporting only summary value, e.g. mean or median rating, might elicit incomplete or even misleading conclusions (e.g., showing "mean rating" in situations where equally large proportion of respondents have chosen the opposite polar adjectives).

To test whether color is significantly more related to a particular pole of emotion, answers were combined on each side of the neutral level of the scale and only non-neutral answers were considered. Chi-square test was used to test the null hypothesis of equal proportions on each side of the neutral response. We admit that using merged scale levels inevitably leads to some loss of information, but we accept this trade-off for the sake of plausibility and accessibility in interpreting results. In addition, the use of different non-parametric (rank-based) tests should essentially give the same conclusions.

To investigate the impact of demographic factors on color-emotion mapping, ordinal regression was used. This approach allows to estimate the effect of each individual factor after adjusting for all other factors. The factors included in the regression model were age, gender, nationality, education level, education field and place of residence. All factors are categorical therefore baseline category is specified when results are reported for each factor. The graphics of estimated regression coefficients (with 95% level confidence intervals) corresponding to log-odds ratio of each particular factor level against the baseline factor, are used to display ordinal regression results. The coefficient above zero is interpreted as an increased probability (compared to baseline) of choosing right-hand side emotion, whereas the coefficient below zero is interpreted as an increased probability of choosing left-hand side emotion from any given emotion pair. The effect size is represented by the distance from zero.

It should be noted that in cases where multiple hypotheses were simultaneously tested no family-wise Type I error correction methods were applied. Thus, it should be taken into account that some significant results can arise due to randomness. Nevertheless, our approach highlights main tendencies.

Spearman correlation coefficient is used to evaluate correlations between individual emotion association pairs and colors due to the ordinal measurement scale.

The analysis was conducted in R (R Core Team, 2018) and figures were produced using the package ggplot2 (Wickham, 2016). The corresponding author upon request will provide the code and data to reproduce the analysis.

3. Results

First, we discuss general findings about relationships between different emotion associations and colors. As expected, patterns of color ratings vary significantly across different emotion associations (Figure 1). Further, we briefly describe each particular emotion association.

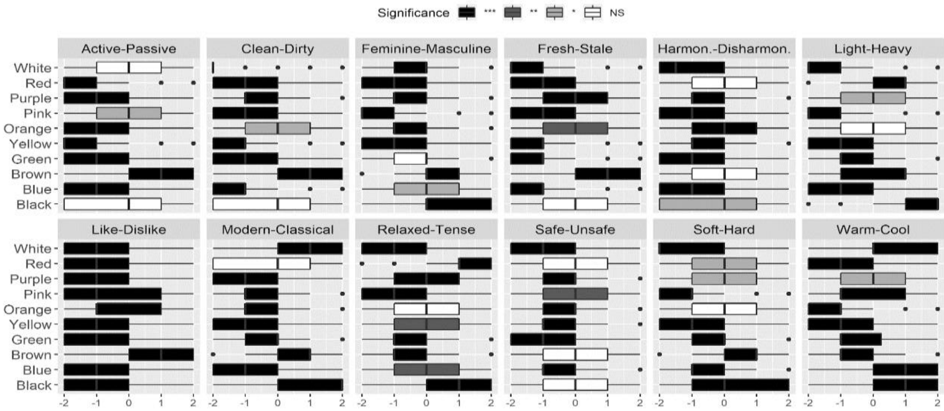


Figure 1. Color rating boxplots grouped by emotions
Numbers on X-axis are according to 5-point rating scale: -2 - Left, -1 - Rather left, 0 - Neutral, 1 - Rather right, 2 - Right. Significantly more responses for one of the directions at the *** 0.1% level, ** 1% level, * 5% level, ^ 10% level; NS - no significant predominance of any direction.

Active-Passive. Red (88%) and yellow (86%) are most frequently rated as active followed by green (70%), blue (67%), purple (68%), and orange (63%). Brown is the only color considered to be strictly passive by the majority of respondents (74%), while just slightly more people considered pink more passive (45%) than active (35%). Black and white are rated equally as both active and passive (accordingly 40%-35% and 32%-37%).

Clean-Dirty. White is almost unambiguously rated as clean (86%) followed by slightly less conclusive responses for blue (81%) and yellow (77%). The rest of the colors are also perceived predominantly as clean with some exceptions - orange is most frequently rated as clean (45%), but around one third (31%) rated it as dirty while black is almost equally rated as dirty (35%) and clean (41%) but brown is the only color considered dirty (65%) by most respondents.

Feminine-Masculine. Pink is most convincingly considered as a feminine color (88%) followed by red (68%), yellow (67%), purple (60%), orange (52%) and white (36%). In contrast, black (46%) and brown (50%) are characterized as the most masculine colors, while a rather large part of participants rated them as neutral (accordingly black 43% and brown 37%). Blue and green are rated as both feminine and masculine (accordingly 26%-37% and 32%-24%). At the same time, similarly as in the case of white or orange, they are typically rated also as neutral (white 59%, green 44%, blue 38%, and orange 37%).

Fresh-Stale. Yellow (83%), blue (82%), white (79%) and green (75%) are most frequently rated as fresh. Brown (71%) is the only color considered as stale significantly more frequently than fresh, while black is classified almost equally often as fresh (28%) and stale (38%). Most subjects rate pink (64%) and red (56%) as fresh, followed by purple (46%) and orange (43%). Orange, similarly as black, is frequently rated also as neutral (neutral ratings are assigned to black 35%, orange 30% and purple 28%).

Harmonious-Disharmonious. According to our data, all colors are rated as rather harmonious (white (70%) is the most convincing followed by green (67%), pink (64%) and blue (61%)) except for brown and red. For these colors a similar number of respondents consider them as either harmonious or disharmonious (accordingly 31%-39% and 37%-36%). Brown (29%), red (28%) and orange (31%) are relatively often rated neutral.

Light-Heavy. Almost all subjects consider pink (86%) and white (82%) as light colors. Also, yellow (72%), blue (67%) and green (52%) have been mostly rated as light while a couple of colors are more often rated as heavy - primarily black (77%) followed by red (58%), brown (51%), and purple (43%). Green (30%) has been comparatively most frequently rated as neutral, and subjects have rated purple and orange as rather light and heavy similarly frequently (accordingly 31%-43% and 42%-31%).

Like-Dislike. Almost all colors are liked by most respondents to a relatively similar degree where blue (72%), green (68%) and purple (66%) were most often positively evaluated. Brown is the only color significantly more disliked by most subjects (57%). In turn, white (11%) and blue (14%) are the least frequently disliked. This scale indicates the color preferences that match the results of previous studies and support the Ecological Valence Idea (e.g., rating brown as most disliked). For a more comprehensive study on preferences in interface environments, see Šķilters et al. (2018b).

Modern-Classical. Most subjects consider black (62%) and white (55%) as distinctively classical colors. Brown is also considered as classical (53%) by most of the participants, but to a lesser extent. All other colors are more frequently considered as modern, except red which is rated as both modern (45%) and classical (36%). Purple, yellow and blue are rated as modern most frequently and least frequently as classical (accordingly 65%-14%, 57%-16% and 56%-17%).

Relaxed-Tense. Pink (71%) and white (62%) followed by brown (51%), green (51%) and blue (45%) are more frequently rated as relaxing colors. The majority of respondents consider red (80%) and black (62%) as tense colors while purple (47%), yellow (47%) and orange (41%) less convincingly but also comparatively frequently rated as tense. Yellow and orange are just slightly more often rated as tense than relaxing (accordingly 47%-31% and 41%-30%) which is a similar tendency in the opposite direction as in the case of blue (31%-45%). This pair of emotion associations is eventually linked to time perception and can be explored further. According to Gorn, et al. (2004), feeling of relaxation is related to the perceived speed of interaction. There is more on this issue in the discussion part of the paper.

Safe-Unsafe. The majority of respondents rates almost all colors as safe rather than unsafe. Green (71%) and white (60%) are considered as safe most frequently and followed by blue (57%) and yellow (54%). Exceptions are black, brown, and red that are considered safe or unsafe to a relatively similar degree (accordingly 38%-39%, 33%-37% and 38%-46%) with red being rated in general as unsafe. Brown (30%), pink (34%), orange (29%), and purple (29%) are rated frequently also as neutral.

Soft-Hard. Here we observe a similar pattern as in Light-Heavy emotion association with pink (78%), white (75%), yellow (65%), and blue (60%) being most frequently rated as soft, whereas brown (52%) and black (48%) being most frequently rated as hard. The same pattern corresponds to orange and purple both of which are rated as rather soft and hard to a relatively similar degree (accordingly 38%-28% and 41%-28%). The exception is red that was more frequently rated as heavy (58%), but with respect to Soft-Hard emotion association, it is rated more often as soft (42%). Also, this emotion association pair has been rated more often neutral for all colors with green (36%), orange (34%) and purple (30%) being rated as neutral most frequently and followed by red (29%) and brown (28%).

Warm-Cool. Orange (81%), yellow (72%) and red (61%) are most frequently rated as warm followed by pink (55%), brown (52%), and green (51%). In contrast, blue (66%), black (51%), and white (48%) are significantly more frequently rated as cool. Purple is rated similarly frequently as warm and cool (accordingly 31%-45%) and white and black are rated as neutral relatively most frequently (accordingly 30% and 29%).

The results allow for the following generalization - most colors seem to induce positive emotion associations. We have also attempted to categorize colors in groups with respect to each emotion (Table 3). This categorization is somewhat arbitrary and demonstrate the following correspondences: Left/Right - more than 50% of respondents have related color with the corresponding pole of emotion; Rather left/Rather right - more people have related color as left (right) than right (left), but less than 50% in total (the colors are ordered according to the size of the difference (e.g. for Warm-Cold emotion, if one subtracts the percentage of respondents associating orange with cold from those associating orange with warm, the difference is larger than the difference making the same calculation with yellow color); Neutral - colors for which the proportion of neutral responses is above 75th quantile from all neutral response proportions; Opposite - colors for which the hypothesis of equal proportions for both emotion poles were not rejected, i.e. there is not enough evidence showing the color is more related to one of the emotion poles than the other. This means that people perceive these colors differently and there is no uniformity among ratings.

Table 3. Color categorization with respect to each color

	Left	Rather left	Rather right	Right	Neutral	Opposite
Wrm-Cl	O Y R Br Pi G		P W	Bl B	W Bl	
Sft-Hrd	Pi W Y B	G R P O	Bl	Br	G O P R Br	
Sf-Usf	G W B Y	P O Pi			Pi Br P O	Bl Br R
Rlx-Tns	Pi W Br G	B	O Y P	Bl R	O	
Mdn-Cls	P Y B O Pi	G		W Br Bl	Br G	R
Lk-Dlk	B W G P Y Bl R Pi O			Br		
Lgt-Hv	Pi W Y B G	O	P	Br R Bl	G	
Hm-Dhm	W G Pi B Y P	O Bl			O Br	R Br
Fr-Stl	B Y W G Pi R	P O	Bl	Br	Bl O P	
Fm-Msc	Pi Y R P O	W	B Bl Br		W G Bl B Br O P	G
Cln-Drt	W B Y G Pi R P	O		Br	R	Bl
Act-Ps	R Y G B P O		Pi	Br	W	W Bl

Left: Left+Rather left > 50%. Rather left: 0% < Left+Rather left < 50% and hypothesis of equal proportions for both emotion poles is rejected. Rather right: 0% < Right+Rather right < 50% and hypothesis of equal proportions for both emotion poles is rejected. Right: Right+Rather right > 50%. Neutral: proportion of neutral responses is above 75th quantile from all neutral response proportions. Opposite: hypothesis of equal proportions for both emotion poles is not rejected (Figure 1). See Table 1 and Table 2 for color and adjective abbreviations.

Next, we rearrange the diagram from Figure 1 and group response summaries by colors in Figure 2.

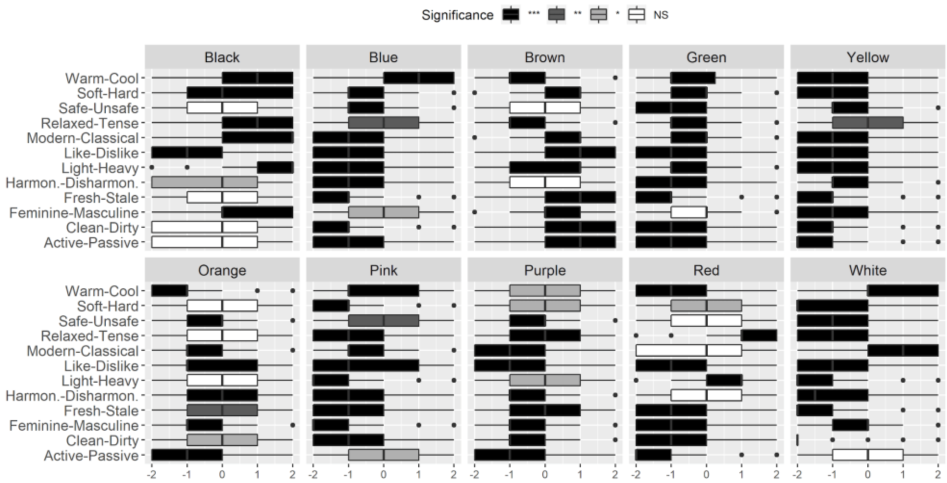


Figure 2. Color rating boxplots grouped by colors

Numbers on X-axis are according to 5-point rating scale: -2 - Left, -1 - Rather left, 0 - Neutral, 1 - Rather right, 2 - Right. Significantly more responses for one of the directions at the *** 0.1% level, ** 1% level, * 5% level, ^ 10% level; NS - no significant predominance of any direction.

We can explore each color in order to elaborate the corresponding emotion association pattern. We can think of this as describing a profile of each color with respect to emotion associations it evokes. In Figure 3 the emotions listed are most frequently associated with each color.

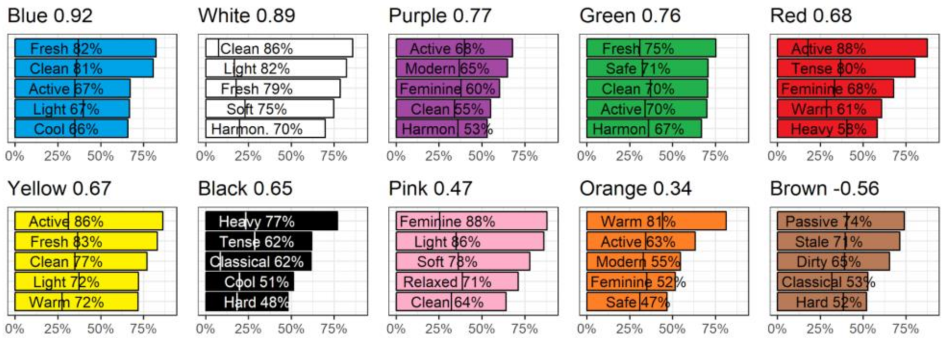


Figure 3. Emotions that are most frequently related with each of the colors
Percentage represents the proportion of moderate (-1 or 1) and strict (-2 or 2) ratings for the emotion specified in each bar. The vertical line stands for the distinction between moderate and strict ratings - area of the bar to the right represents the proportion of strict ratings. Mean value of Like-Dislike score is displayed for each color (with opposite sign, so larger score means more Like), and colors are ordered by this value.

In terms of differences and similarities among colors, we can observe (Figure 2) that blue and green share similar patterns in ratings; however, blue is considered to be cool, but green - a rather warm color. In most aspects yellow is also comparable with blue and green, although it is also considered a warm, feminine, and more active color. Pink and white are frequently rated similarly but the difference is that white is marked as cool and classical, while pink is rather warm and modern. If purple and orange are compared, we can observe that the former is a much warmer color, while the latter is generally more liked by respondents and rated more as modern.

Next, the correlations were explored to answer two questions about color-emotion ratings overall:

Which emotions are rated similarly considering all colors together?

Which colors are rated similarly considering all emotions together?

Figure 4a exemplifies the first question. If the correlation coefficient of two emotions is sufficiently large, we can conclude that there exists an association between ratings of the two emotions. Larger Spearman correlation coefficient values here mean that individuals who rate particular color more positively (negatively) for one emotion, will likely rate other emotions positively (negatively) as well. Thus, for example, we observe that Clean-Dirty and Fresh-Stale are the most correlated emotion associations. This means that if a subject thinks that some color is clean, she/he will most probably think that it is also a fresh color. We see that there is a group of colors that are mutually correlated - Light-Heavy, Soft-Hard, Fresh-Stale, Clean-Dirty, Harmonious-Disharmonious. An interesting observation concerns Like-Dislike scale, which corresponds to preference rating. According to our results, Like-Dislike strongly correlates with Harmonious-Disharmonious and to a slightly less extent with Fresh-Stale and Clean-Dirty emotions. This means that color preferences (as expressed by Like-Dislike) is a reliable predictor for some other emotion association pairs. (According to previous research, the dimension of pleasantness/pleasure generally seems to be correlated with preference (Hulbert and Owen, 2016)). We can also see that there are emotions that are not correlated, e.g. Relaxed-Tense and Modern-Classical or Light-Heavy and Active-Passive. For these pairs of color-emotion mappings, knowing the rating of one color-emotion mapping does not help to predict the rating of another color; these cases indicate the lack of significant statistical connections between corresponding color-emotion associations.

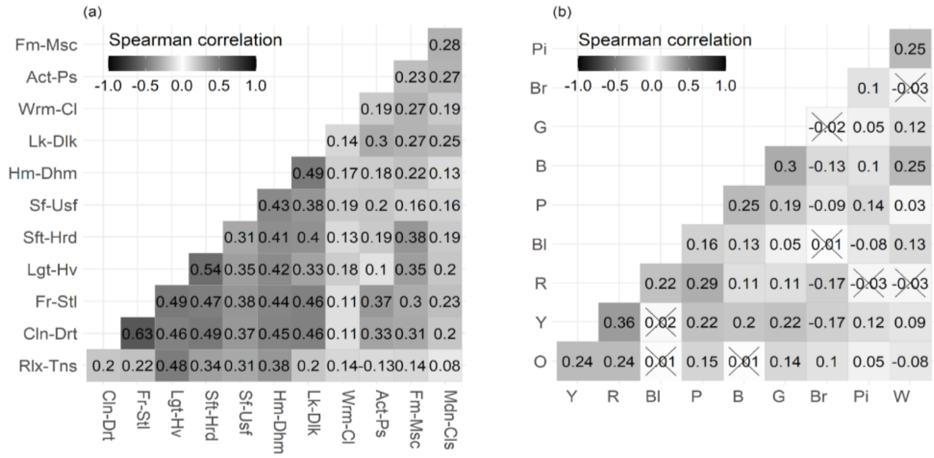
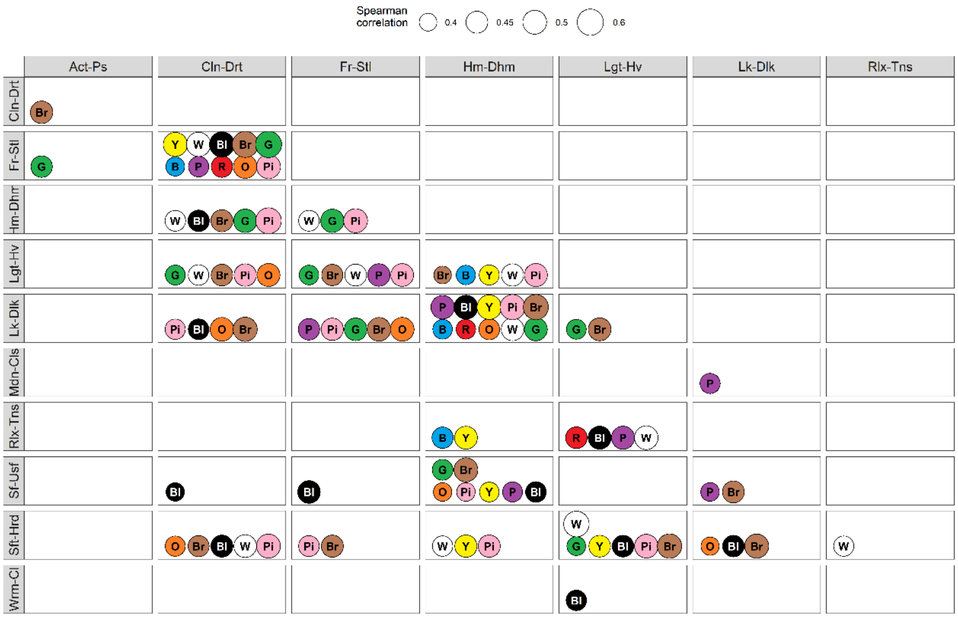


Figure 4. Correlations of ratings between emotions (a) and colors (b)
Non-significant (at 5% level) correlations are crossed out. See Table 1 and Table 2 for color and adjective abbreviations.

A more detailed correlation analysis is summarized in the Table 4 showing correlations between emotions with respect to the tested colors. The table summarizes colors with the relatively highest correlation coefficients - higher than 0,4.

Two emotion association pairs have strong correlations for all colors - Fresh-Stale in respect to Clean-Dirty and Like-Dislike with respect to Harmonious-Disharmonious. These emotion association pairs have been evaluated relatively similarly with respect to the tested colors. In addition, the emotion pair Safe-Unsafe has strong correlations with the emotion pair Harmonious-Disharmonious for most colors (7 colors from 10). However, there are emotion association pairs that do not have or have a comparatively very few associations with other tested emotion association pairs that could be represented by correlation coefficients greater than 0.4. For example, Feminine-Masculine is not shown in Table 4, because this emotion association pair has not been evaluated similarly to other tested emotion association pairs with respect to the chosen colors. Other emotion association pairs that have fewer relatively stronger correlations with other emotion association pairs are Modern-Classical (only purple correlates with Like-Dislike), Warm-Cool (only black correlates with Light-Heavy) and Active-Passive (brown has association with Clean-Dirty and green has association with Fresh-Stale). Most frequently such relatively stronger correlations for the tested emotion association pairs correspond to colors brown (16 cases), pink (14 cases), white and black (12 cases) as well as green (11 cases).

Table 4. Correlations of ratings between emotions with respect to each color



See Table 1 and Table 2 for color and adjective abbreviations.

These results are crucial and can be practically applied when color schemes for interface environments are changed. To secure the same or similar emotional effect as with the previous colors a new selection can be made among the ones that strongly correlate. (Of course, additional difficulties might arise due to the task dependency on color categorization (Zariņa et al., 2019) and impact of color combinations, which is currently investigated in another study.)

Now we can also check whether there is any interesting correlation structure between colors (Figure 4b). Large Spearman correlation coefficient for two colors means that these colors are rated similarly across all emotions. We can see in Figure 4b that most correlation coefficients between colors are rather low, which means that usually colors are rated differently for at least some emotions. However, there are some color pairs that tend to be positively correlated, e.g. orange-yellow, orange-purple, green-blue, and green-orange. Higher correlation coefficients for these colors can be tentatively explained by looking at Figure 2 - these colors share similar distribution patterns.

More detailed correlations between colors with respect to tested emotion association pairs are summarized in the Table 5. The general tendency indicates that the correlations between colors with respect to emotion association pairs are not strong - we separated a group with relatively higher correlations (greater than 0,3) included in the Table 5, but even such moderate correlations are not frequent. This indicates that different colors are generally linked with emotions rather differently with respect to tested emotion association pairs. As exceptions are red and yellow that have such relatively higher correlations for 6 emotion association pairs out of 12, and colors blue and green that have

5 such relatively stronger correlations with respect to tested emotion association pairs. The emotion association pairs that most frequently are characterized by pairs of correlated colors are Clean-Dirty (4 cases), Fresh-Stale, Feminine-Masculine and Modern-Classical (3 cases for each). For these emotion association pairs more colors have been evaluated as relatively similar.

Table 5. Correlations of ratings between colors with respect to each emotion pair

Pearson correlation 0.35 0.40 0.45

	Black	Blue	Green	Yellow	Pink	Purple
Green		Cln-Drt Rlx-Tns Lgt-Hv Fm-Msc Fr-Stl				
Yellow			Mdn-Cls			
Orange				Fm-Msc		
Pink						Wrm-Cl
Purple		Sft-Hrd Wrm-Cl				
Red		Cln-Drt		Fm-Msc Cln-Drt Act-Ps Hm-Dhm Fr-Stl Sf-Usf		Mdn-Cls Cln-Drt
White	Mdn-Cls				Fr-Stl Lgt-Hv	

See Table 1 and Table 2 for color and adjective abbreviations.

These results can be practically applied when color schemes for interface systems are changed or substituted but there is a need to keep a similar atmosphere (that could cause an interaction comfort in users) in respect to emotion associations that are changed once colors are changed.

A final step in our analysis concerns the effects of demographic factors in color-emotion mappings. As mentioned earlier, we have investigated the impact of six demographic variables - age, gender, nationality, education level, science field and place of residence. What follows is a brief description of findings for each demographic variable.

In Figure 5, we see that in few cases gender is a significant factor in color emotion mapping. Pink is the color for which ratings seem to be most affected by gender - we see seven significant differences between genders. Generally, men relate pink with distinctly unfavorable emotions. There are some emotions that are comparatively more influenced by gender - Safe-Unsafe, Like-Dislike and Feminine-Masculine. However, we might conclude that, according to our data, gender shows impact only in a few cases of color and emotion association. Thus, although our sample contains significantly more female respondents, the general conclusions about color-emotion mapping from Figures 1 and 2 would not be substantially different if the sample was better balanced.

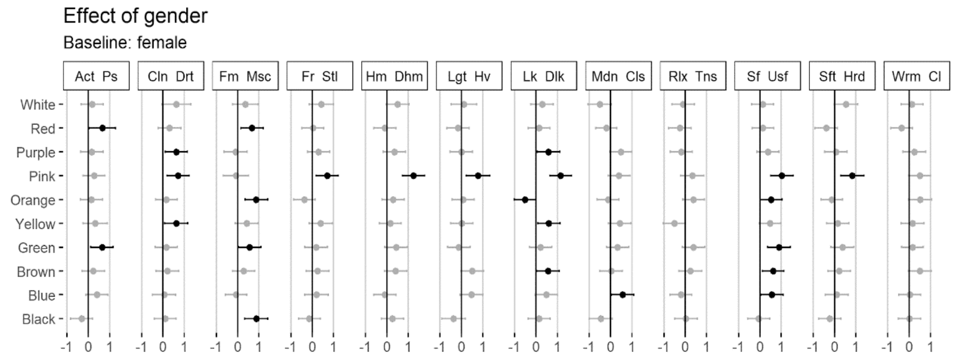


Figure 5. Comparison of color-emotion mapping between male and female participants. Ordinal regression coefficients with 95% confidence intervals (CI) are plotted. Coefficient above 0 is related with increased probability of right-hand side emotion with respect to baseline. Black colored CIs do not overlap 0. See Table 1 and Table 2 for color and adjective abbreviations.

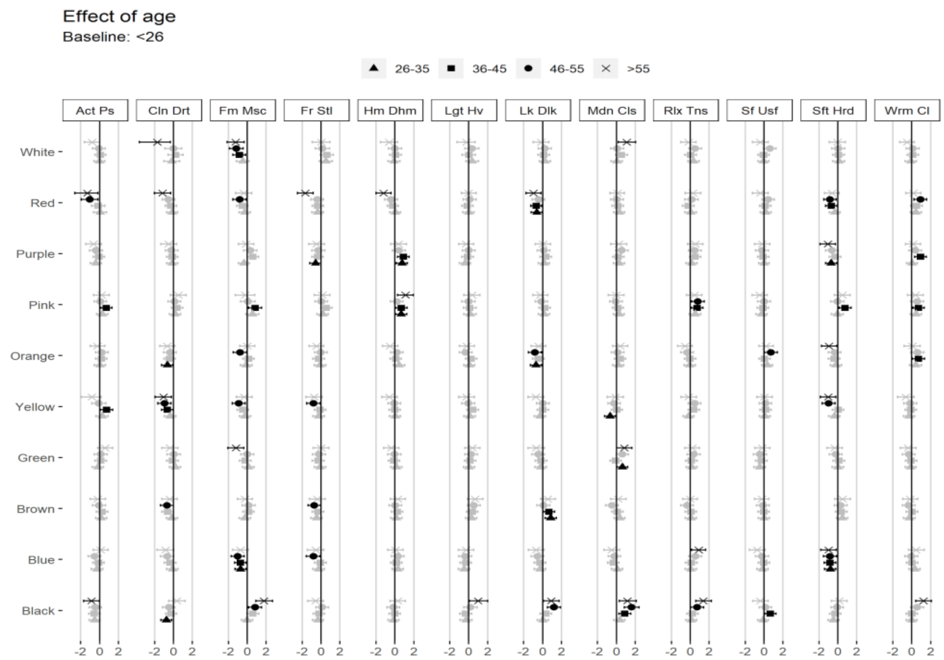


Figure 6. Comparison of color-emotion mapping between age groups
Ordinal regression coefficients with 95% confidence intervals (CI) are plotted. Coefficient above 0 is related with increased probability of right-hand side emotion with respect to baseline. Black colored CIs do not overlap 0. See Table 1 and Table 2 for color and adjective abbreviations.

It can be seen that age is also not a significant factor in most cases (Figure 6). We may observe the same trends demonstrated previously (Zariņa et al., 2019; Šķilters et al., 2018a) - elderly people tend to consider the black color more classic and generally like it less than younger people. Or that elderly people tend to consider red as more harmonic, fresh and active. However, the rest of the significant results are harder to be interpreted with respect to age differences.

In Figure 7 nationality as a factor on color-emotion mapping is investigated (other nationalities are merged into the Russian group because most non-Latvian participants were intentionally chosen from the Russian-speaking population). Again, only in very few cases we observe that nationality has an impact on the relation between emotions and colors. We can see that green is generally liked more by Russians and induce emotions that are more positive. There are few other cases where nationality changes the extent to which colors are mapped to certain emotions - for example, Latvians consider yellow as more harmonic and Russians consider pink as more unsafe. The problem is that these very few and somewhat marginal differences are difficult to interpret conclusively and generalize. Eventually color-emotion mappings are more culture-independent (than perceived harmony in case of color combinations) (Ou et al., 2018) but we do not have many culturally different subjects in our sample to assume something more conclusive in this respect (both Latvian and Russian population in our sample live in the same geographic area and at least to some extent belong to the same cultural space).

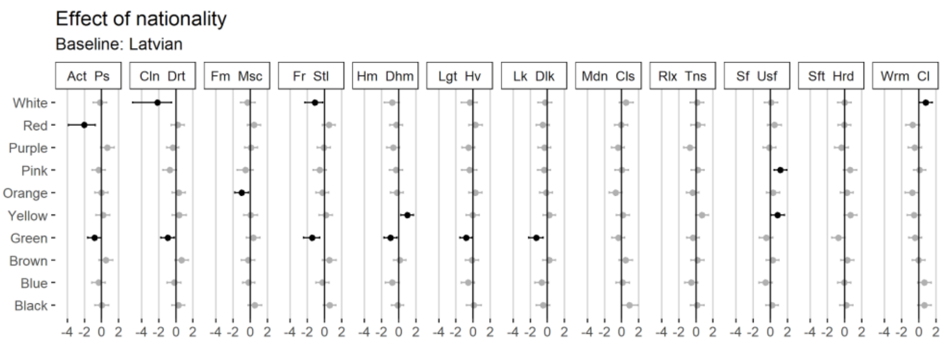


Figure 7. Comparison of color-emotion mapping between Latvian and other (mainly Russian) participants
Ordinal regression coefficients with 95% confidence intervals (CI) are plotted. Coefficient above 0 is related with increased probability of right-hand side emotion with respect to baseline. Black colored CIs do not overlap 0. See Table 1 and Table 2 for color and adjective abbreviations.

Figure 8 visualizes the effect of education level on color-emotion mapping. We see very few significant coefficients and taking into account multiple testing problem (inevitable false positive results) they should be interpreted with caution.

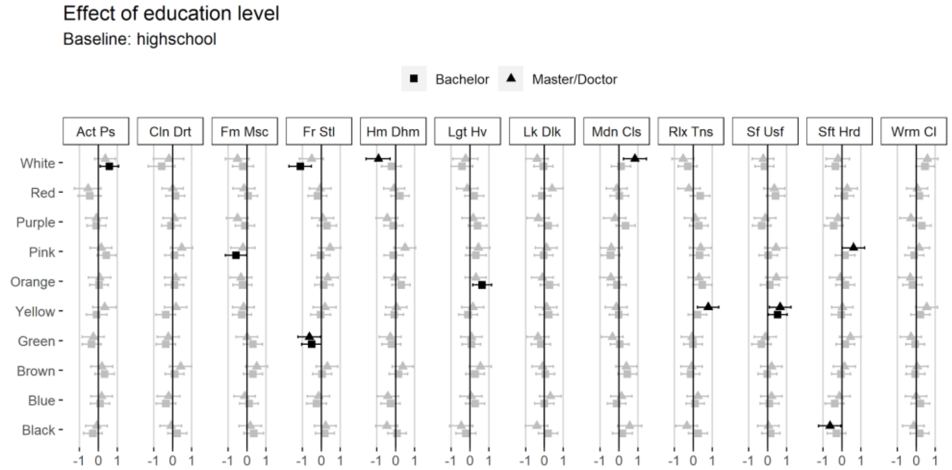


Figure 8. Comparison of color-emotion mapping between participants with different education level

Ordinal regression coefficients with 95% confidence intervals (CI) are plotted. Coefficient above 0 is related with increased probability of right-hand side emotion with respect to baseline. Black colored CIs do not overlap 0. See Table 1 and Table 2 for color and adjective abbreviations.

Some significant place of residence effects may be found for Harmonious-Disharmonious and Clean-Dirty emotions (Figure 9). These emotion-association links eventually occur because of the differences in environment and lifestyle between participants living in country or capital; this would also support the idea of ecological valence of colors. Also, pink seems to induce more negative emotions for participants from country.

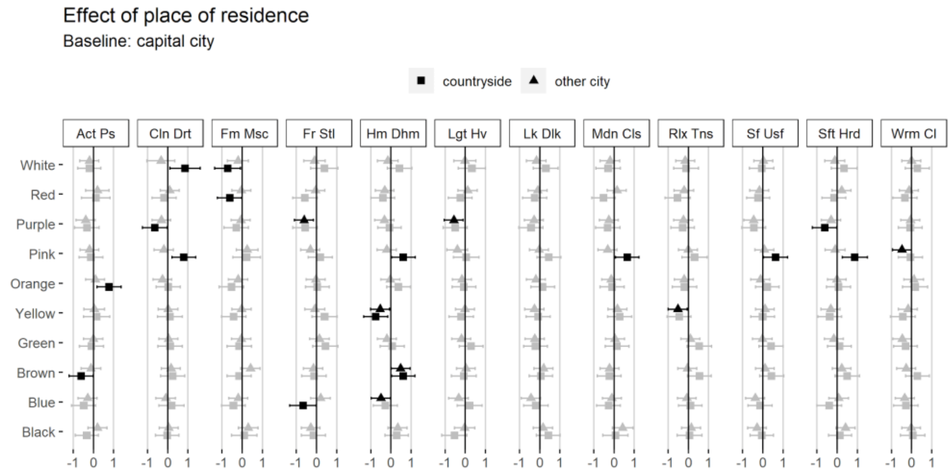


Figure 9. Comparison of color-emotion mapping between participants from different places of residence

Ordinal regression coefficients with 95% confidence intervals (CI) are plotted. Coefficient above 0 is related with increased probability of right-hand side emotion with respect to baseline. Black colored CIs do not overlap 0. See Table 1 and Table 2 for color and adjective abbreviations.

Finally, we look at science field as a potential variable influencing color-emotion mapping (Figure 10). We can observe that pink color is more positively valued by participants from non-STEM fields and some other rather standalone observations, such as, non-STEM participants consider purple as more modern or red as safer than STEM participants. However, we can also observe that there are very few effects of the field of science on color-emotion mappings that could be used as a strong basis for uncontroversial explanations and generalizations.

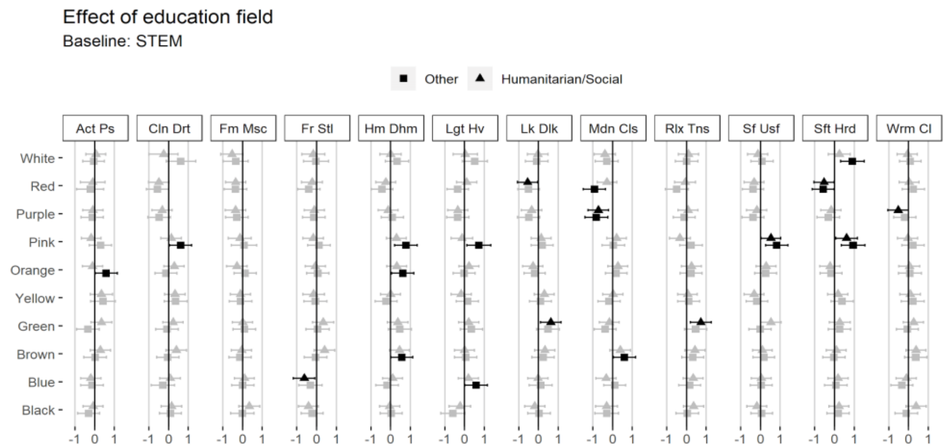
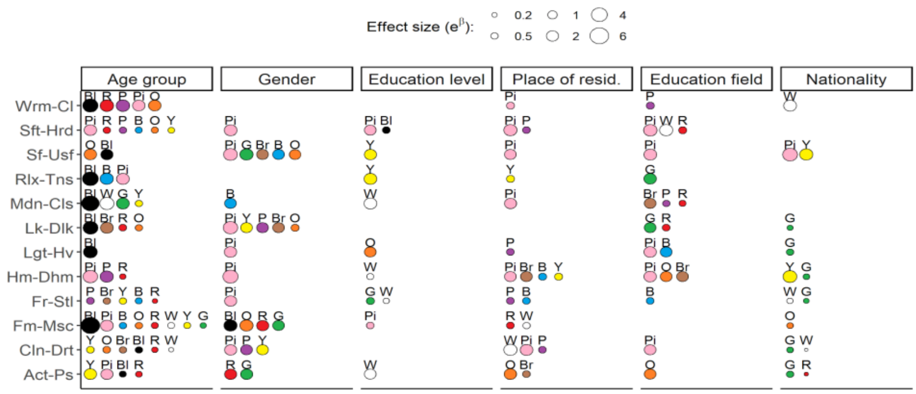


Figure 10. Comparison of color-emotion mapping between participants from different education fields

Ordinal regression coefficients with 95% confidence intervals (CI) are plotted. Coefficient above 0 is related with increased probability of right-hand side emotion with respect to baseline. Black colored CIs do not overlap 0. See Table 1 and Table 2 for color and adjective abbreviations.

As a final step of investigation of demographic factor influences, we summarized information on where most significant effects (5% significance level, no correction for multiple testing) are found for each emotion. Summary is visualized in Table 6.

Table 6. Significant demographic factors for each color-emotion pair



Circles are ordered by size of corresponding regression coefficient. Circle size describes the relative size of the effect. See Table 1 and Table 2 for color and adjective abbreviations.

4. Discussion and conclusions

Our study provides systematic and ecologically valid links between a set of simple colors (Table 1) and some emotion associations (Table 2). Some mappings are strong and reliable while some are weak or ambiguous. However, in general there seems to be a pattern of correlations that can be reasonably applied when an interface system is (a) designed for inducing a particular emotional reaction or association, (b) re-designed in terms of dominating color schemes (colors that induce a compatible or similar emotional reaction can be chosen). We also tested demographic impacts on color-emotion mapping but observed only a few significant ones.

Our results can be used to improve user motivation in information seeking tasks because according to extensive research results (summarized by Savolainen (2014)) emotional reaction supports motivation for information seeking. Our analysis of colors can be used as mediators for elaborating better interface environment for seeking information in virtue of induced emotion associations.

Despite the overall structure of mappings and correlations between colors and emotions our study has shown, we agree with Simmons (2015) that the reactions to colors might be both stereotypical and personal but, nevertheless, we assume that it is technically impossible to distinguish between stereotypical and personal associations in color ratings, and the fact that some reactions to colors are personal or stereotypical does not change the meaning of the strong mappings between colors and emotions (but can be an explanation for the differences in those cases where there are weak correlations).

Further, a couple of remarks about some of our findings and some generalizations. Our results regarding the blue as the most preferred color (Figure 3) are consistent with the majority of the work on color preferences and color categorization within different methodological settings and theoretical frameworks (Bakker et al., 2013; Schloss and Palmer, 2010; Valdez and Mehrabian, 1994), for a consistent cross-cultural evidence see Madden et al. (2000); for a previous study within a similar setting see Šķilters et al. (2018a).

Taking into account that the feeling of relaxation tends to induce a greater perceived quickness (Gorn et al., 2004), our results regarding tense/relaxed colors might be used to modulate time perception while using interfaces. However, more experiments that are detailed are necessary here to provide a comprehensive answer regarding time and color perception as mediated by emotion association of relaxation.

Results in ratings in the dimension of color preferences and pleasantness/unpleasantness seem to be basically consistent with most of the findings by Simmons (2015) who had a different but to some extent more precise system of measurements and has used a larger set of stimuli colors (for a discussion see also Hurlbert and Owen (2016)).

Although, according to our results, age seems to be a sensitive determinant of affective reactions to certain colors, the impact is somewhat weak because of the sample structure (for a more comprehensive study of the impacts of age on color categorization within interface environments see Šķilters et al. (2018a)). Variability and dependency of color categorization on age is also supported by empirical evidence showing that emotion regulation depends on age (Stanley and Isaacowitz, 2013).

Why are there the systematic differences in ratings of emotion associations? Although we assume that object evaluations and emotional valences attached to objects can shape preferences to colors themselves (as argued by Ecological Valence theorists (Schloss and Palmer, 2010)), another related explanation might be that colors are experientially valenced with respect to certain objects and events in the past but that this shapes the preference of (a) those colors abstracted from concrete objects and situations, and (b) other objects in that color. This, however, does not imply that the emotional valence is transferred directly from object to color but rather and more plausibly that emotion associations are transferred (color preferences are unidimensional whereas emotions are multidimensional; the more emotion associations are preferred, the more color is emotionally positive and emotionally preferred; see for a discussion Hurlbert and Owen (2016)). This would mean that the colors are liked not only because of the objects that in general are in those colors but also because of the richness (overall higher ratings in different scales of emotion association measurement) of associations that are attached to them. This might be the case of blue or red. Additionally, salience and saturation tend to support the increase in color preference (see Valdez and Mehrabian (1994); Simmons, (2015)).

Finally, although we have not explored individual differences among raters in detail, we assume that there might be additional individual factors causing variability in color-emotion ratings. This idea is supported by convincing empirical evidence that color ratings and emotional mappings tell something about the rater herself/himself. For instance, depressed raters would eventually rate dark colors higher; this can be generalized in a congruence principle: “people like colors with emotional associations that match the self’s emotions” (Robinson et al., 2015, p. 671; see also Fetterman et al., 2014; Taylor et al., 2013). This in general indicates dependency of color preferences on the mood of raters (Bakker et al., 2013).

Apart from the mood of the rater there are other additional constraints that might shape color and emotion mappings and color categorization in general: e.g., task dependency and personal characteristics of the participant (Bakker et al., 2015; Šķilters et al., 2018a). Further, although a different study would be necessary (with different variables and stimuli), it seems that our results also fit into the Kobayashi (1981) (see table III) approach arguing that there are variety of systematic impacts mapping human associations (containing color preferences, emotions, associations and symbolism but also general preferential motivation) with the theory of image that, in turn, is mapped with what he calls the theory of semantics (relating human with her environment, objects, life style etc).

The main contribution of the current study is to describe a set of color-emotion mappings for interface usability analysis and improvement based on a set of experiments. Our study extends and transforms classical color-emotion approach by Ou et al. (2004a, b) into the analysis of ecologically valid interface environments by describing patterns for color-emotion mappings for inducing particular emotional association and adjusting color schemes in the context of demographic factors.

Our study contains some limitations and future research directions as well. First, color stimuli could in future be tested in varying dimensions of brightness and saturation (as we know from Valdez and Mehrabian (1994) and Simmons (2015)) – for example, brighter colors tend to induce more positive emotion association, whereas the opposite seems to be the case with darker colors (Hemphill, 1996).

Further, our study used a limited set of colors. Although our rationale was to include robust colors only (because of quasi-experimental online setting which could cause effects in different displays, lighting etc.), there might be more nuanced effects when a larger range of color stimuli is used where brightness and saturation are varied. Also, a larger set of emotion terms might be applied (not only the canonical emotion-associations). Finally, although we did ask whether the subjects have normal color vision, we did not apply

Ishihara color test due to time limits but which might be applied in a future study in lab conditions.

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