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Cognitive performance and emotion are indifferent to ambient color

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Abstract
Folklore has it that ambient color has the power to relax or arouse the observer and enhance performance when executing cognitive tasks. We picked a number of commercially available colors that allegedly have the power to alter cognitive performance and the emotional state, and exposed subjects to them while solving a battery of cognitive tasks. The colors were "Cool Down Pink", which is said to produce relaxing effects and reduce effort, "Energy Red", allegedly enhancing performance via increased arousal, "Relaxing Blue", which is said to enhance attention and concentration, as well as white as a control. In a between-subjects design, a total of 170 high school students carried out five tasks (number series completion, mental rotation, and memory for word categories, word pairs, and geometrical figures) while exposed to one of the four colors. The emotional state of the subjects was measured before the beginning and at the end of the experiment. The ambient colors did not have the predicted effects, neither on cognitive performance nor on the emotional state of the participants.

KEYWORDS
Baker-Miller Pink, cognitive performance, color, emotion, interior design

1 | INTRODUCTION

In popular science and the media, assumptions about psychological and behavioral effects of color are ubiquitous. For instance, a particular shade of pink, so-called Baker-Miller Pink, achieved a certain notoriety as it has been used to calm down aggressive prison inmates at a naval correctional facility in Seattle,[1,2] where two prison guards named Baker and Miller first installed a pink holding cell based on reports by Schauss and colleagues that looking at pink reduces muscle strength and aggressive behavior.[1,3] In the wake of these reports, prison cells at several correctional facilities in the US, Switzerland, and Germany have received fresh coats of pink paint. Schauss and colleagues posit that color has direct effects on physiological parameters, such as blood pressure and skin conductance, which in turn causes relaxation (in the case of pink) or activation (in the case of red). For instance, Pelligrini and Schauss[3] recorded reduced grip strength in a pink as opposed to a blue environment (see also Refs. 4 and 5). However, several studies failed to replicate negative effects of pink on grip strength compared to blue, white, or other hues.[6–12] A reduction of aggression in a pink prison cell was reported by two studies,[13,14] whereas a recent experiment found no evidence for such an effect.[15]

The current study is concerned with the claim that ambient color can significantly alter cognitive performance and the emotional state of the observer. So far, both effects of stimulus color (e.g., the color of a test sheet) and ambient color (the paint of an office or a class room) have been reported to influence measures of *cognitive performance*. With regard to stimulus color, Mehta and Zhu[16] changed the background hue of a computer monitor used to collect performance data on proofreading, anagram solution, and creativity tasks. With lightness and saturation being equal across hues, a red background (in comparison to blue) interfered with creative tasks but not with the detail-oriented proofreading. Similarly, the background color of a paper-and-pencil test sheet[17,18] as well as the status bar color of a computer-based test[19] were reported to influence measures of cognitive performance. In addition, Elliot et al.[20] found that brief exposure to red color before the experiment led to poorer performance solving anagrams and analogies. Even the mere processing of the word "red" compromised performance.[21] Quite a few such effects caused by a fleeting color impression have been reported over the years (for a review see Ref. 22). However, note that some attempts to replicate such effects of color exposure have failed. For instance, Smajic et al.[23] found no effects when adding a green or red cover sheet to a multiple-choice exam. Similarly, Larsson and von Stumm[24] found no effects when using red versus green ink for a coding number on the top right corner of a Raven's progressive matrices test booklet. Steele[25] was also unable to replicate the findings by Mehta and Zhu.[16]

In studies with an explicit focus on learning environments, words written in red color have been found to lower rates of retrieval in secondary school students in comparison to gray words.[26] With regard to screen color, Yamazaki[27] reported that brighter background colors lowered test scores in a computer-based English test in comparison to darker colors, and Brooker and Franklin[28] found that children scored worse in tests of cognitive performance when the presentation screen was red, as compared to numerous other screen colors. Additionally, handwriting performance of students with ADHD benefited when their writing paper was colored red whereas healthy students did not.[29]

Is it possible to enhance cognitive performance in contexts of education by selecting an optimal ambient color of the learning environment (e.g., the class room)? Evidence from experiments that investigated the effects of ambient color in real or simulated (office) work environments is mixed at best. Kwallek and Lewis[30] and Kwallek et al.[31] reported that participants in a red office made fewer errors in a proofreading task than did groups tested in a white office. Küller et al.[32] found no difference in proof-reading performance between red and blue office spaces, and Ainsworth et al.[33] reported no difference in typing performance between office rooms with red, blue, and white walls. Kwallek et al.[34] found the effect of color to depend on personality: so-called "high screeners" who can more easily ignore environmental stimuli profited from red office spaces, whereas low screeners performed better in a blue-green office. Although these results were only partly confirmed by a follow-up study,[35] they indicate a potential link between effects of color on cognitive performance and effects of color on *emotion*. Highly saturated ("vivid") colors result in higher arousal than ("pale") colors with low saturation.[36–39] In addition, at equal lightness and saturation, red causes higher arousal than green or blue.[38] The valence dimension of emotion (i.e., positive vs. negative) is also influenced by all of the three color dimensions.[37,38]

The results by Kwallek et al.[34] suggest that effects of room color on cognitive performance could be due to differences in arousal. According to the Yerkes and Dodson[40] "law", medium levels of arousal often result in higher performance than low or high levels of arousal. Data by Al-Ayash et al.[41] are compatible with such a relation between arousal and performance. While the hue of a colored screen did not affect cognitive performance in a reading comprehension task, saturation did. More saturated colors increased reading comprehension compared to less saturated colors. In addition, heart rate was altered by the hue and, to a weaker extent, by saturation. Red and yellow color increased heart rate compared to a blue color condition, and higher saturation corresponded to a (non-significantly) higher heart rate. Thus, Al-Ayash et al.[41] observed better performance in color conditions causing higher arousal. Note, however, that a relation between effects of color on emotion and performance was not observed in all studies.[18,32]

In sum, when reviewing the literature concerning effects of color on measures of cognitive performance and emotion, one is confronted with an incoherent picture. Thus, general guidelines for the application of color in real-life settings can hardly be derived from the evidence provided so far. From an applied perspective, the current state of research is discouraging, since practitioners in the field of color design must rely on robust results in order to improve learning and working environments.

In the present study, we investigated the effects of three commercially available interior colors advertised to have specific effects on cognitive performance and emotion in comparison to a neutral white. The first three colors were purchased from a Swiss paint company (Dold AG) advertising an Emotional Color System™.[42] We chose these colors, because, according to the company's advertisement, they distinctively influence both cognitive performance and the emotional state of persons exposed to them. According to the advertisements, Cool Down Pink™ should reduce aggressive behavior and anxiety, as well as encourage confidence, empathy and tenderness. Recommended areas of application include penitentiaries, psychiatric wards, maternity wards, and baby rooms (http://www.dold.ch/pim/dold-bau-emotionalcolorsystem-cool-downpink, accessed December 14, 2016). Energy Red™ is advertised as having positive effects on adrenaline production, energy, assertiveness, capacity for love, and capacity for movement. Recommended areas of application include sports facilities, bedrooms, bars, and adult entertainment (http://www.dold.ch/pim/dold-bau-emotionalcolorsystem-energyred, accessed December 14, 2016). Relaxing Blue™ is said to enhance concentration, conscientiousness, and serenity.

FIGURE 1 Left panel: Photo of the examination room with eight booths placed on separate desks, set up in four rows of two workplaces each. The four workplaces on the left and the four workplaces on the right were centered beneath the left and the right continuous ceiling-light-strips, respectively. Right panel: Photos of the insides of the colored booths. Colors from top left to bottom right: “Cool Down Pink”, “Energy Red”, “Relaxing Blue”, and white

Recommended applications include schools, universities, conference rooms, offices, and production halls (http://www.dold.ch/pim/dold-bau-emotionalcolorsystem-relaxingblue, accessed December 14, 2016). In addition to these colors, we chose a neutral fourth color, a standard white interior color bought from a local do-it-yourself store, to serve as control. In a learning environment, we measured the performance of high school students on a variety of cognitive tasks (number series completion, mental rotation, and memory tests for word categories, word pairs, and geometrical figures). Past studies have typically chosen only one or two tasks rather than looking at a larger range of performance measures. The use of various performance measures within the same experiment should make it possible to provide converging evidence if color does indeed have consistent effects on cognitive performance. To investigate potential relations between emotional and cognitive effects of the colors, we measured the emotional dimensions, arousal, valence, and dominance (e.g., Ref. 43).

2 | METHOD

2.1 | Subjects

A total of 170 high school students (87 women, 82 men, 1 subject did not specify the gender), aged from 16 to 26 years (M = 18.58, SD = 2.01), participated in the study. According to the Declaration of Helsinki, all subjects gave their written informed consent. For subjects younger than 18 years, written informed consent was obtained from their parents. All subjects were not aware of the intention of the experiment and were debriefed after the experiment.

2.2 | Stimuli and apparatus

We constructed eight wooden booths (0.80 m width × 0.80 m depth × 0.80 m height), closed on three sides, for the experiment (see right panel of Figure 1). The booths were positioned on eight desks in four rows of two desks each. All workplaces had comparable lighting conditions (see left panel of Figure 1).

The interior walls of each booth were painted in one of four different colors (see right panel of Figure 1). Two booths each were painted in “Cool Down Pink”, “Energy Red”, “Relaxing Blue”, and white. Table 1 displays the colorimetric values of the four booth colors, as measured by means of a spectroradiometer (Specbos 1201). Note that we have used commercially available indoor colors in which lightness and saturation varied considerably across hues. We will return to this issue in the Discussion. Measurements were taken with the object’s surface directly aligned to the light source (0°) and tilted by 45° relative to the optical axis of the spectroradiometer (alignment 0/45) as well as with the object’s surface tilted by 45° relative to the light source and directly aligned (0°) to the optical axis of the spectroradiometer (alignment 45/0) (cf., Ref. 45). Two D65 lamps (GTI ColorMatcher 11 W) were used as light source. Across all measurements, the distances between the measurement point on the object’s illuminated surface and between the light source and between the measurement point and the spectroradiometer were 66 and 30 cm, respectively. The illuminance level of the measurement points (as measured with a luxmeter with the probe head parallel to the orientation of the surface) was 360 lx for the 0/45 alignment and 280 lx for the 45/0 alignment.

2.2.1 | Measures of cognitive performance

During the experiment, subjects were presented with five paper-and-pencil cognitive-performance tasks. We used one task on reasoning, one on mental rotation, and three memory tasks to allow for convergence of measures. Recent studies have focused on retrieval of rather complex information.[27,46,47] Although some of these color effects on memory are quite remarkable, when studied in isolation, they reveal

TABLE 1 Colorimetric values of the four booth colors for both measurement alignments (0/45 and 45/0)

Color	Alignment	X	Y (cd m^{-2})	Z	L*	S	h (deg)
"Cool Down Pink"	0/45	61.64	54.50	58.56	78.75	29.96	359.82
	45/0	50.84	45.42	48.70	73.17	28.64	0.09
"Energy Red"	0/45	28.45	19.95	8.59	51.78	71.19	35.75
	45/0	24.99	18.37	9.64	49.95	65.76	33.62
"Relaxing Blue"	0/45	13.31	13.92	34.45	44.12	60.26	271.32
	45/0	12.14	12.59	29.18	42.14	57.17	272.77
White	0/45	88.60	93.59	94.80	97.47	3.82	93.65
	45/0	70.24	74.17	75.31	89.00	3.72	93.15

Columns *X*, *Y*, and *Z* display the CIE XYZ tristimulus values according to the 10° CIE 1964 standard observer,[56] columns *L** and *h* display the lightness and hue values according to the CIE LCh 1976 system,[57] column *S* displays the saturation values calculated from the LCh 1976 chroma (*C**) values: $S = C^{*2}/(C^{*2} + L^{*2})^{1/2} \cdot 100\%$ (cf., 44Lübbe, 2013).[44] *L**, *S*, and *h* are specified relative to a D65 white point.

little about potential effects of task type[16] and difficulty.[48] Therefore, we chose to use tasks of varying difficulty that tap into different processes involved in recognition.

Task 1 (numerical reasoning) consisted of ten number sequences (e.g., −7 6 −8 7 −9 _?). Participants were asked to fill in the number that should come next in the sequence. The time limit for Task 1 was 2 min.

Task 2 (visual memory) was adopted from the LMT (Lern- und Merkfähigkeitstest;[49]). Subjects saw 10 different drawings of two-dimensional geometrical figures for 1 min and were asked to memorize them. The experimenter administered the recognition phase of Task 2 after the completion of Task 5. During recognition, subjects had to identify the 10 drawings shown in the learning phase in a set of 30 geometrical figures, which contained the ten learned figures as well as 20 new figures similar in style. The time limit for recognition was 1.5 min.

In Task 3 (cued recognition of categories), subjects learned five words each from five different categories (cities, animals, jobs, countries, and plants; German: Stadt, Tier, Beruf, Land, Pflanze) for 3 min. The 25 words differed in their initial letter such that each initial letter occurred only once. After the recognition phase of Task 2, subjects had to indicate (by circling the correct category name) for each of the 25 initial letters to which category the corresponding word belonged (e.g., A—city/animal/job/country/plant). The time limit for recognition was 5 min.

Task 4 (mental rotation) consisted of two mental rotation exercises adopted from an intelligence test (Intelligenz-Struktur-Test 2000 R;[50]). In each exercise, subjects saw five perspective drawings of cubes with different symbols on the visible surfaces of the cubes and 10 further perspective cube drawings, which were rotated versions of the first five drawings. For each of the 10 rotated versions, subjects had to find its unrotated counterpart from the first line by marking it with the appropriate label of the original drawing. The time limit for Task 4 was 3 min.

Task 5 (cued recognition of word pairs) was also taken from the LMT.[49] Subjects were presented with a list of 30 animal-adjective word pairs (e.g., dog—cruel) and had to learn as many as possible within 4 min. The recall phase of Task 5 was carried out after the recognition phase of Task 3. During recognition, subjects had to identify the correct adjective among three adjectives presented next to the respective animal name. The answer sheet contained all of the 30 animal names and their associates/distractors in random order (e.g., dog—cruel/comfortable/lousy; German: Hund—grausam/angenehm/mies). The time limit was 5 min.

2.2.2 | Self-ratings of emotion

Subjects self-assessed their current emotional state before and after processing the tasks using the SAM (self-assessment manikin;[51]) scales, which measure the three emotional dimensions valence, arousal, and dominance on non-verbal nine-point scales (cf., Figure 3).

2.3 | Design and procedure

The participants were tested in groups of eight students in two high school classrooms. Figure 2 illustrates the procedure. Before entering the classroom with the colored booths, subjects self-assessed their current emotional state on the three SAM scales outside the booths in a separate classroom (baseline). Then they were randomly assigned to one of four booth colors. While conducting the experimental tasks, 44 participants were exposed to "Cool Down Pink" (21 women, 23 men; $M_{age} = 19.07$, $SD_{age} = 2.39$), 43

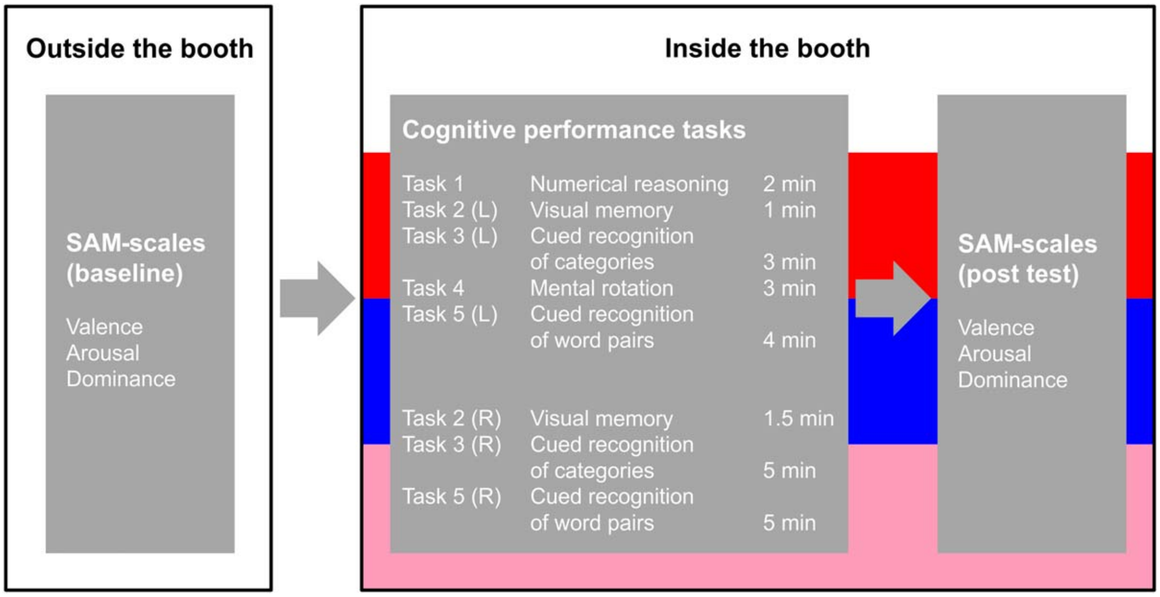

FIGURE 2 Illustration of the procedure. Arrows represent the passage of time. (L): learning phase, (R): recognition phase

participants to "Energy Red" (23 women, 20 men; $M_{age} = 18.35$, $SD_{age} = 1.93$), 39 participants to "Relaxing Blue" (22 women, 16 men, 1 unspecified; $M_{age} = 18.18$, $SD_{age} = 1.62$), and 44 participants to the white control paint (21 women, 23 men; $M_{age} = 18.66$, $SD_{age} = 1.94$). Thus, in each test group of eight subjects all four color conditions were represented, with two booths for every condition. The four groups did not differ significantly in the proportion of women and men, $p = 0.761$ (Fisher's exact test, two-tailed), and mean age, $F(3,166) = 1.61$, $p = 0.188$ (univariate ANOVA). During the experimental session, subjects uncovered the test and answer sheets on the table inside each booth on the commands of the experimenter. When the allotted time had elapsed, the experimenter asked to stop the respective task, to cover the answer sheet, and to advance to the next task. After completing the paper-and-pencil tasks, subjects again rated their current emotional state (SAM scales), while remaining seated inside the booths (post test). The experiment lasted ~30 min.

3 | RESULTS

We first report the results of the SAM ratings before (baseline) and after (post test) the cognitive-performance tasks, followed by the results of the cognitive-performance tasks.

3.1 | SAM ratings

Three subjects failed to fill in the rating scales completely and, thus, were excluded from the further analyses regarding the SAM ratings. The remaining subjects in the four groups did not differ significantly in terms of the proportion of women and men, $p = 0.806$ (Fisher's exact test, two-tailed), and their mean age, $F(3,163) = 1.72$, $p = 0.164$ (univariate ANOVA). The mean SAM ratings are depicted in Figure 3.

We conducted a doubly-multivariate repeated-measures analysis of variance with booth color ("Cool Down Pink", "Energy Red", "Relaxing Blue", and white) as between-subjects factor, time of measurement (baseline, post test) as within-subjects factor, and the three SAM scales (valence, arousal, dominance) as dependent measures.

The effect of booth color was not significant, Pillai trace $V = 0.04$, $F(9,489) = 0.72$, $p = 0.69$, $\eta^2_p = 0.01$, indicating that the four randomly assigned groups were comparable with respect to their mean emotional state at both times of measurement. Likewise, the booth color × time of measurement interaction was not significant, $V = 0.03$, $F(9,489) = 0.63$, $p = 0.77$, $\eta^2_p = 0.01$. This indicates that the subjects' emotional state was not significantly influenced by the manipulation of the booth color. There was, however, a significant effect of the time of measurement, $V = 0.24$, $F(3,161) = 17.34$, $p < 0.001$, $\eta^2_p = 0.24$. In a post hoc analysis, we calculated univariate repeated-measures analyses of variance (rmANOVA) with the same factorial design separately for each emotional dimension. In comparison to baseline measurement, we found both significantly lower valence and dominance ratings at the post-test measurement, $F(1,163) = 45.80$, $p < 0.001$, $\eta^2_p = 0.22$ and $F(1,163) = 13.44$, $p < 0.001$, $\eta^2_p = 0.08$, respectively. In contrast, the arousal ratings did not change significantly over time, $F(1,163) = 0.01$, $p = 0.94$, $\eta^2_p < 0.001$. Taken together, at the second time of measurement (post test) when subjects had accomplished the cognitive-performance tasks,

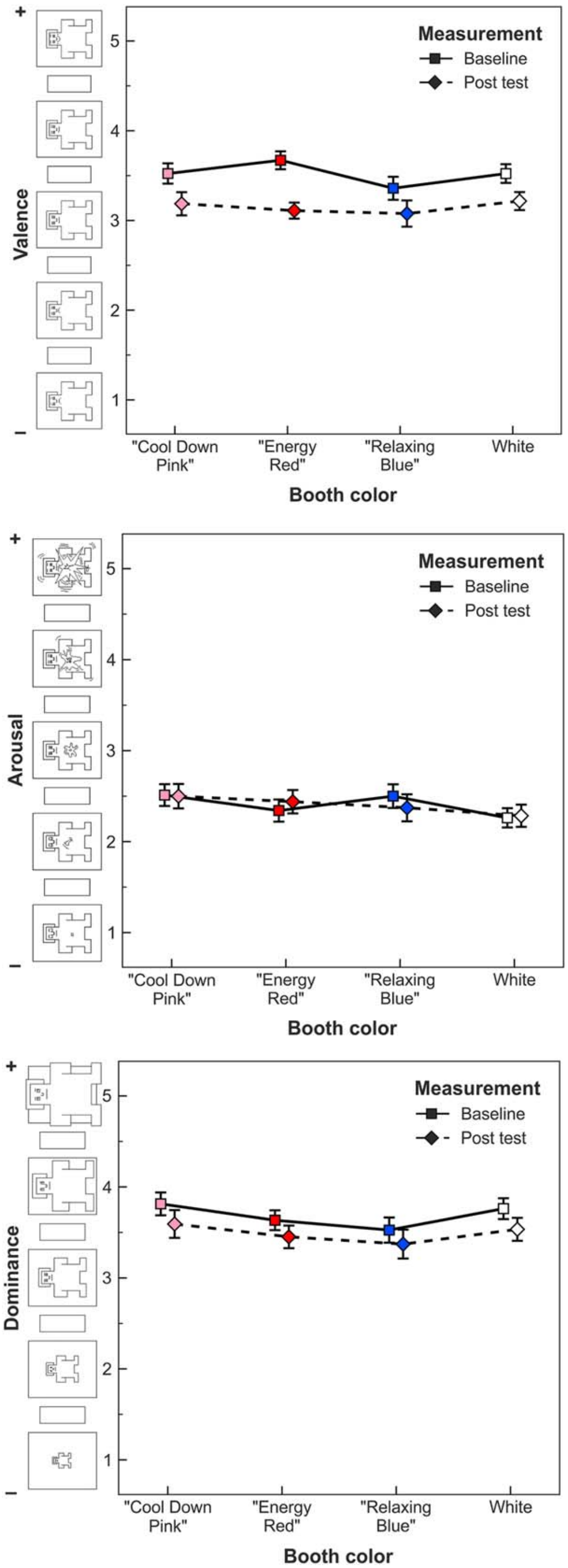

FIGURE 3 Mean emotion ratings on the SAM scales for valence (upper left panel), arousal (upper right panel), and dominance (bottom panel), as a function of booth color and time of measurement. Squares: baseline. Diamonds: post test. Error bars indicate the 95% confidence interval (CI) of the 43 subjects in the "Cool Down Pink" condition, the 41 subjects in the "Energy Red" condition, the 39 subjects in the "Relaxing Blue" condition, and the 44 subjects in the white control condition, respectively

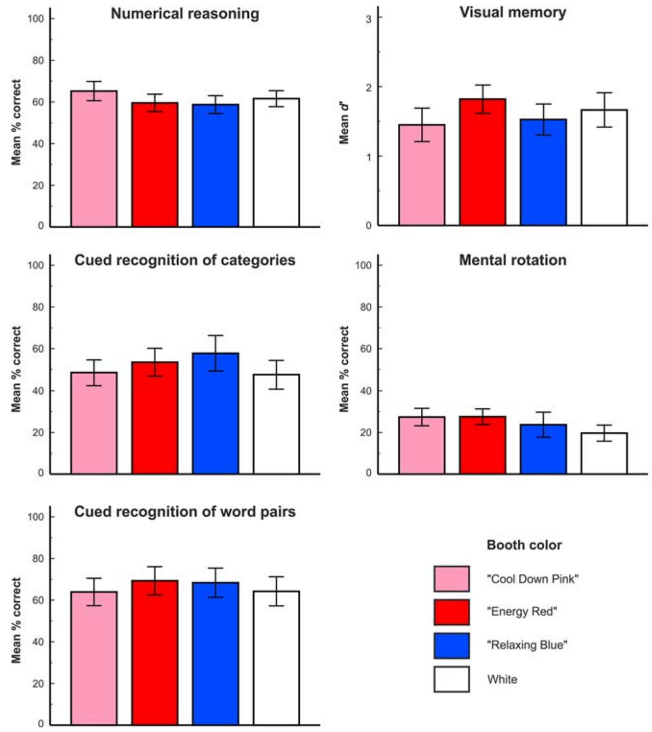

FIGURE 4 Mean performance scores in Tasks 1–5, as a function of booth color: numerical reasoning (top left panel), visual memory (top right panel), cued recognition of categories (middle left panel), mental rotation (middle right panel), and cued recognition of word pairs (bottom panel). Error bars indicate the 95% CI of the 44 subjects in the "Cool Down Pink" group, the 43 subjects in the "Energy Red" group, the 39 subjects in the "Relaxing Blue" group, and the 44 subjects in the white group, respectively

they felt less happy and less dominant than at the first time of measurement (baseline).

3.2 | Cognitive-performance tasks

For the visual memory task, we analyzed performance in terms of the sensitivity index d'.[52] Previously learned geometrical figures (targets) marked by the participants were taken as "hits", and not previously learned figures (distractors) marked by the participants were taken as "false alarms". The sensitivity index was computed as $d' = z_{\mathrm{Hit}} - z_{\mathrm{FA}}$, where $z_{\mathrm{Hit}} = \Phi^{-1}(N_{\mathrm{Hit}}/N_{\mathrm{target}})$, Φ^{-1} is the standard-normal inverse cumulative distribution function, N_{Hit} is the number of hits, N_{target} is the total number of targets. Similarly, $z_{\mathrm{FA}} = \Phi^{-1}(N_{\mathrm{FA}}/N_{\mathrm{distractors}})$, where N_{FA} denotes the number of false alarms and $N_{\mathrm{distractors}}$ denotes the total number of distractors.

For all other tasks (numerical reasoning, mental rotation, cued recognition of categories, cued recognition of word pairs), we analyzed the percentage of correctly answered items with regard to the total number of items.

The mean scores in the cognitive-performance tasks are depicted in Figure 4.

Did the booth color influence task performance? Descriptively, the five performance measures did not point towards a consistent change in subjects' performance due to the manipulation of booth color. Considering Figure 4, it becomes visible that none of the colors led to a general increase or decrease across the different performance measures. Looking at "Cool Down Pink", for example, performance was slightly enhanced in the Numerical Reasoning Task as well as in the Mental Rotation Task, but it was below the grand mean in the three remaining tasks. We ran a multivariate analysis of variance (MANOVA) with booth color ("Cool Down Pink", "Energy Red", "Relaxing Blue", and white) as between-subjects factor. The five performance measures were the dependent variables. The MANOVA showed a significant albeit small effect of booth color, $V = 0.17$, $F(15,492) = 1.92$, $p = 0.02$, $\eta^2_p = 0.06$, indicating an effect of color exposure on task performance. As a post-hoc analysis, univariate ANOVAs with the same factorial design were conducted separately for each task. We merely found a significant effect of color on subjects' performance in the Mental Rotation Task, $F(3,166) = 2.93$, $p = 0.04$, $\eta^2_p = 0.05$. As depicted in Figure 4, we found the highest performance in the pink and red condition, medium performance in the blue condition, and lowest performance in the white control condition. However, all other ANOVAs showed no significant effect of condition on task performance (all P-values $> .10$).

4 | DISCUSSION

High school students completed reasoning, mental rotation, and memory tasks in test booths painted in three different colors, which had been advertised to have specific effects on cognitive performance and emotion, and in a white reference condition. With respect to cognitive performance, there was no consistent advantage or disadvantage of any of the colors tested. Having said this, we did find a small but significant effect of color on mental rotation performance: Subjects performed slightly better with red and pink backgrounds as compared to blue or white backgrounds. This is the opposite than what might have been expected on the basis of the color properties communicated by the color manufacturer, according to which the blue color should help students to concentrate. Also, the pink color was supposed to have relaxed the subjects, whereas the red should have excited them. Thus, one would have expected the blue and red color, for example, to induce opposite effects, even if uncommitted as to whether relaxation should provide a push toward or away from a would-be performance optimum. It should also be noted that the effect sizes were rather small.

What do our findings imply for the question whether ambient color has an influence on cognitive performance? We have, for the first time, taken a look at a more or less comprehensive set of performance tests. Consequently, we can definitely rule out a general and consistent performance enhancing or inhibiting effect of color. The alleged power of red to affect cognitive performance was not visible for numerical reasoning, visual or verbal memory, or object recognition in our experiment. Subjects in the red condition neither performed better nor worse than subjects in the blue, pink, or white condition. Likewise we failed to find evidence for increased or reduced performance in pink or blue ambient light in all of our tasks. Thus, a direct effect of color on cognitive performance was not observable in a situation that called for attention to be sustained for 30 min. A limitation of our experiment is that we cannot rule out with certainty that using, for example, a red compared to a blue wall color in a classroom might have an effect on cognitive performance when students spend hours or even months in this environment.

One potential explanation for the absence of stronger effects on cognitive performance could be that in our experiment it is very unlikely that the attention of the subjects was mainly focused on the colored test booth rather than on the cognitive test sheets. This may have reduced the effect of color on performance. However, essentially the same can be said about experiments in which the only color stimulus was a colored small subject code printed on the top or bottom of the test sheet (e.g., Refs. 20 and 24). Here, context effects might have played a role. Red-colored text on a test sheet could be associated with red marks indicating errors and failure. Thus, the reported decrease in performance in the red condition could be due to a specific association between red marks on a written exam and low performance, rather than due to a general red-induced performance reduction. In any case, from an applied perspective, our results cast doubt on the assumption that specific wall colors could have effects of practical relevance on cognition.

As discussed in the Introduction, it has been argued that color does not directly affect performance but rather changes the subject's emotional state, which may then affect cognitive performance, for instance by inducing an optimal or sub-optimal level of arousal. Based on the literature, we expected lower arousal in the blue than in the red color environment because the blue color was darker and less saturated than the red color, and because of the reported effects of hue.[38] This expected difference in arousal corresponds to the effects suggested by the color manufacturer. The pink color was less saturated than red and blue, with a hue angle located between red and blue, and a higher lightness than red and blue. As all of the three color dimensions have an effect on arousal,[38] it is difficult to predict an exact arousal level for pink. Because saturation is taken to have a relatively strong effect on arousal,[37–39] we would have expected relatively low arousal in pink environments, again compatible with the specifications provided by the color manufacturer. However, we were unable to detect any emotional changes induced by the colors. Our subjects felt happier with anticipation as compared to their emotion ratings after the test, but the color condition to which they were assigned had no significant effect on their emotional state. Pink did not reduce arousal ratings, neither did red increase them. Nor could we detect a relaxing effect of blue. Thus, the emotional effects often attributed to color did not surface in our experiment.

Three reasons could explain this difference from other existing studies. First, we used commercially available wall colors in which saturation and lightness varied across hues (see Table 1). Saturation decreased from red to blue to pink, and lightness decreased from pink to red to blue. However, we argue that this confound should have rather increased than decreased a potential effect of booth color. Note that, for example, the red stimulus was both more saturated and brighter than the blue stimulus. As outlined above, both higher lightness and saturation values are associated with higher arousal (e.g., Ref. 38). From this perspective, it seems very unlikely that using constant saturation and lightness across hues would have increased an effect of booth color. Second, the exposure times of about 30 min might have been too long to capture transient color effects on emotion. In most studies on emotional effects of color, each color stimulus is typically viewed only for about 10 sec to 1 min (e.g., Ref. 38). Third, as discussed above, in contrast to studies where the task is to view a color and then to rate the own emotional state, in our experiment it is very unlikely that the attention of the subjects was directed to the colored test booth rather than to the cognitive test sheets. Thus, the results might indicate a difference between emotional effects of the color of the stimulus subjects attend to and effects of the color of the environment. Compatible with this view, some previous experiments that tested participants in colored office spaces likewise did not observe significant effects of color on emotion,[32,33,53] although other studies reported some effects.[31,34] Taken together, our data neither show a systematic effect of the color of the learning environment on the emotional state of students, nor do they suggest that the small effect of color on mental rotation performance, which we observed, was mediated by emotion. Speaking again from an applied perspective, our experiment did not support the relatively strong effects of wall color on the emotional state advertised by the color manufacturer. Because of the limited sample size, our findings can of course not be taken as evidence against any effect of booth color on the subjects' emotional state.[54] Another limitation is that we collected only self-report measures of emotion, and no physiological measures. However, because effect sizes for manipulations of emotion are typically smaller in the latter than in the former measures,[38,55] it appears unlikely that physiological measures would have indicated a stronger emotional effect of booth color than the effects obtained with the SAM ratings.

Taken together, our results add to the relatively mixed evidence concerning effects of color on cognitive performance. They do not show a significant effect of wall color on emotion. Notwithstanding the obvious need for additional research, the practical implications suggested by our data are that the use of color for the purposes of enhancing cognitive performance in an educational context appears to be questionable. Thus, interior design considerations probably need not worry about lasting effects of ambient color on cognitive performance or emotional state.

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