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Color-validity associations put to the test: Examining the robustness of red-false and green-true associations in the Implicit Association Test.

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Abstract

Although there is a considerable amount of research on color associations, not much is known about color-validity associations. Initial work with a Stroop task suggests automatic green-true and red-false associations. In the present work, we were interested in testing the generalizability of these associations by using a different procedure, the *Implicit Association Test* (IAT). In four IAT-experiments we investigated red-false and green-true associations across different color contexts and stimulus materials. Participants categorized objects presented in two different colors as well as true and false statements (Experiment 1), true and false mathematical equations (Experiment 2), or *true*-related and *false*-related words (Experiment 3). The hypothesized green-true and red-false associations were observed in all experiments when both red and green stimuli appeared within the same task but varied in tasks involving only one of both colors and a respective control color. The use of conceptual color representation instead of colored objects (Experiment 4) did not produce a clear pattern. A final, registered experiment aims at finding an explanation in valence- and/or salience-asymmetries as potential confounds of IAT effects.

Keywords: color associations, Implicit Association Test (IAT), validity, valence, salience

Introduction

Colors play an important role in everyday life. While this role is sometimes limited to pure aesthetics (e.g., when choosing a color for your wall paint), color may also carry semantic meaning (e.g., a red traffic light signals “stop” while a green one means “go”). Color meaning, however, often depends on the context (Elliot & Maier, 2007). For example, red can be a sign of failure in an achievement context (Elliot et al., 2007; Elliot et al., 2009) while it might signal attractiveness in romantic contexts (Elliot & Niesta, 2008). Moreover, color associations can also vary across cultures and population groups. For example, Hong et al. (2020) found that, similar to studies with Western participants, Chinese college students associate red with failure and green with success, but that the opposite is true for Chinese shareholders. This illustrates that color associations are not necessarily evolutionary prepared but may also be learned (Elliot & Maier, 2007).

Whatever the nature of color-meaning associations, previous research has generally found opposing effects of the colors red and green. For example, Pravossoudovitch et al. (2014) examined red and green as associates for danger and safety in a Stroop-like task. The results showed that danger-related words were categorized faster when displayed in red than in other colors while the presentation of safety-related words in green did not have strong effects. The observed associations of red and danger as well as green and safety also might be related to other domains like financial decision making: Kliger and Gilad (2012) found that participants who were primed with the color red evaluated probabilities of loss under uncertainty higher as participants who were primed with the color green, whereas subjective probabilities of gains were attenuated. Similarly, red seems to elicits inhibition and avoidance motivation in a lot of contexts while green as its perceptual complement has the opposite effect, however, being less pronounced (Elliot et al., 2009; Hochman et al., 2018).

Following the stream of research differentially examining the meaning of red and green in different contexts, Nadarevic et al. (2021) tested whether people associate red with the

attribute *false* and green with the attribute *true*. Using a modified Stroop task, the authors found that participants were faster and more accurate when categorizing falsity-related stimuli in red and truth-related stimuli in green than vice versa. However, there were also some moderators of these effects. First, color-validity associations were more pronounced when participants had to provide speeded responses and when participants had to categorize words instead of sentences. Second, color-validity effects only appeared when red and green were present in the same context. In contrast, no color-validity associations were found in contexts that only comprised red and gray stimuli or green and gray stimuli, respectively. The latter finding suggests that the context specificity of color associations also extends to the color context, i.e., the presence of other colors in the same context.

Color-context effects had also been reported by Schietecat et al. (2018b), who had examined color-valence association with the *Implicit Association Test* (IAT, Greenwald et al., 1998). The IAT measures the differential association of two target concepts (e.g., two different colors) with the two polar opposites of an attribute (e.g., positive versus negative valence). This is done by pairing reactions to concepts and attributes on either the same key or different keys in a categorization task and then comparing reaction times. The idea is that categorizing representatives of associated concepts and attributes with the same key is easier than categorizing them with different keys. In the study by Schietecat and colleagues, color-validity associations differed depending on the contrasted colors in the IAT. When red and green were contrasted, the IAT indicated red-negative/green-positive associations. In contrast, no associations were found when red was contrasted with blue. The authors explained this finding with the *dimension-specificity hypothesis* (Schietecat et al., 2018a). This theory proposes that associations between concrete concepts and abstract concepts can in principle be based on different semantic dimensions. In a specific context, however, the association is based on the most salient dimension. In the case of color associations, this means that different color contexts can stress different dimensions among evaluation, potency, and activity. Associations based on

those dimensions then rely on the *polarity correspondence principle*: Potentially associated target concepts (here colors) have to form polar opposites on the activated dimension. This, for example, seems to be the case on the evaluation dimension for red and green but not for red and blue (Schietecat et al., 2018b). Instead, red and blue seem to form polar opposites on the activity dimension, as demonstrated by effects in an IAT contrasting calmness and aggression as well as enthusiasm and relaxation.

In light of the findings of Nadarevic et al. (2021) and Schietecat et al. (2018b), the goal of the present research was to test whether we would also find evidence for red-false and green-true associations when measuring these associations with the IAT instead of the Stroop task. Moreover, we were interested in possible color-context effects. While the original IAT study by Greenwald et al. (1998) measured associations of insects and flowers with pleasant and unpleasant attributes, subsequent studies have often used the IAT to measure prejudice and racial bias (for a meta-analysis, see Greenwald et al., 2009). In this context, the IAT has also been helpful for explaining the effects by considering general color associations. For example, Smith–McLallen et al. (2006) discovered that racial bias (i.e., more positive associations of White participants toward faces of White individuals compared to faces of African American individuals) can be partially explained by an implicit preference for the color white over the color black, as measured by the IAT. This is supported by other IAT studies showing that lightness influences valence evaluation (Meier et al., 2004; Schietecat et al., 2018a). However, the IAT has also been used to measure color associations that go beyond pure color preferences. For example, Wu et al. (2018) used the IAT to measure the associations of red and social status compared to several control colors. They found that pairing reaction keys for high-status logos and red shapes led to faster reactions than high-status logos sharing reaction keys with a control color across samples from the UK and China. Additionally, the studies by Schietecat et al. (2018b) demonstrate well how different versions of an IAT can also be useful for examining

the underlying dimensions and mechanisms of different color meanings and the effects of color context.

The following series of experiments aims at replicating red-false and green-true associations found by Nadarevic et al. (2021) by using the IAT. Participants' task was to categorize truth- and falsity-related materials as well as representatives of red, green, and a control color. We varied control colors and materials across experiments to test for effects of color context and to be able to generalize across materials. All data and materials are publicly available on the Open Science Framework (OSF; <https://osf.io/pfdkb/>). For the already conducted Experiments 1 to 4, we will report how we determined our samples sizes, all data exclusions, all manipulations, and all measures. Moreover, we plan to conduct a final, registered experiment to clarify the contribution of IAT-specific confounds on color-validity associations.

Experiment 1

Experiment 1 examined color-validity associations with the IAT by means of three different color combinations (red-green vs. red-yellow vs. green-yellow). Yellow served as control color to allow for comparisons across color contexts, respectively. Based on the assumption that people associate red with false and green with true, we defined IAT blocks with response mappings congruent to these associations as *congruent blocks* and blocks with responses mappings incongruent to these associations as *incongruent blocks*.

Methods

Design

All participants completed three color-IATs in a row (red-green, red-yellow, green-yellow) with the order of these IATs counterbalanced according to a Latin square. Additionally, the order of the critical blocks within the IATs (congruent vs. incongruent block first) also varied across participants. Key mapping ("true" left vs. "true" right first) changed across IATs for each participant, splitting participants into two groups depending on initial key assignment. The experiment thus had a 3 (color-IAT: red-green, red-yellow, green-yellow) $\times$ 3 (IAT order:

order 1 vs. order 2 vs. order 3) $\times$ 2 (congruency order: congruent vs. incongruent block first) $\times$ 2 (key-mapping order: “true” left vs. “true” right first) mixed design, with color-IAT being the only within-subject factor. Participants’ *D*-scores, indicating the direction and strength of the IAT effects, served as the dependent variable.

Participants

Based on an a-priori power analysis with G*Power (Faul et al., 2007), we determined a target sample size of 36 participants in order to have sufficient power for testing an IAT’s mean *D*-score with a one-sample *t*-test (one-tailed). The input parameters for the power analysis were a target power of .90, a conventional significance level of $\alpha = .05$, and an expected IAT effect of $d = .50$. Participants were recruited at the University of Mannheim. Thirty-eight participants (28 female, 10 male) with a mean age of $M = 24.3$ ($SD = 7.1$) years took part in the experiment. All participants proved normal color vision in the Ishihara’s color vision test.

Materials

Twenty statements containing exemplar-category assignments of the form “*X* are *Y*” (e.g., “dogs are animals”; “trees are fish”) served as stimuli for true/false categorizations (see Nadarevic et al., 2021, for similar materials). Statements were created based on ten categories and 20 exemplars, of which ten exemplars belonged to their stated category (true statements) and ten did not (false statements). Materials representing potentially associated colors consisted of 30 pictures of naturalistic single-colored objects. For each of the three colors (green, red, yellow) ten pictures depicted different prototypical objects (e.g., a kiwi, a lobster, a banana) in the same hue. Pictures were taken from Naor-Raz et al. (2003) and from the internet according to copyright.

Procedure

The study was conducted in the laboratory. After giving informed consent, participants were tested with a short version of Ishihara’s test for color-deficiency (Ishihara, 2003), provided demographic information, and completed three color-IATs (red-green IAT, red-yellow IAT,

and green-yellow IAT) separated by a 30 s. break. The order of IATs was counterbalanced. Each IAT consisted of seven blocks in line with the standard IAT procedure described by Greenwald et al. (2003).

In *Block 1*, colored objects appeared in one of two possible colors on a white computer screen. In sum, 20 colored objects (ten per color) were presented subsequently in random order in the center of the screen. Participants' task was to categorize the object's color as fast and as accurately as possible by pressing a left response key (*d*) or a right response key (*k*). The color-key mapping was counterbalanced across participants. If the response was correct, the next object appeared after an intertrial interval of 500 ms. If the response was incorrect, a black X appeared along with the request to press the other key as quickly as possible. *Block 2* was similar, except that the participants had to indicate the validity of 20 statements (ten true and ten false ones) displayed in random order. The mapping of response keys (left vs. right) to response categories (true vs. false) was again counterbalanced. *Block 3* combined both tasks from the previous blocks. That is, participants had to respond to colored objects and statements presented in random order. Each response key now represented two categories (e.g., left key for green and true; right key for red and false). Participants practiced this combined task for 20 trials. Subsequently, they moved on to *Block 4*, the first test block comprising 40 trials with all 20 objects and 20 statements presented in random order. In *Block 5*, participants again categorized 20 colored objects, but with a reversed color-key mapping compared to the previous blocks. *Block 6* was a further combined block of statements and objects categorization, but with the color-key mapping of the preceding block. Hence, compared to the first combined block, *true* and *false* now shared the response key with the opposing target color. Participants practiced this task for 20 trials before moving on to *Block 7*, the test block comprising 40 trials. Table 1 provides a schematic representation of the IAT procedure.

Table 1.

Schematic representation of the IAT procedure using the red-green IAT as an example.

Block	Description	Sample Screen
1	Color-practice block (20 trials)
2	Validity-practice block (20 trials)
3 + 4	Combined-practice block (20 trials) + test block (40 trials)
5	Color-practice block (20 trials)
6 + 7	Combined-practice block (20 trials) + test block (40 trials)

Note. Colors and labels displayed in the top corners indicate the mapping of response categories to response keys (left vs. right). Key mapping was counterbalanced between participants.

Finally, participants filled out a questionnaire on explicit color-validity associations. The questionnaire asked if participants associated any colors with truth or falsity and if so, asked them to name the colors.

Results

Computation of IAT scores

For this and the following experiments, we measured the strength and direction of IAT effects by means of *D*-scores. The *D*-score is the standard IAT measure proposed by Greenwald et al. (2003) and represents the difference between the congruent and incongruent IAT blocks divided by their pooled standard deviation. Importantly, for the calculation of *D*-scores, RTs for *all* combined blocks (i.e., practice and test blocks) are considered. Likewise, we will report mean RTs for congruent and incongruent IAT blocks across practice and test blocks. For this and the following experiments, we calculated the so-called *D1*-score (see Greenwald et al., 2003, for more details on different *D*-score variants) with the R-package *implicitmeasures* (Epifania et al., 2020). In doing so, RTs were defined as the time it took participants to press the correct key and we excluded individual trials longer than 10 000 ms. Moreover, we excluded participants whose RTs were shorter than 300 ms for more than 10% of all trials. We will report on excluded participants when applicable. CIs were computed with the R-package *effectsize* (Ben-Shachar et al., 2020). CIs for Cohen's *d* refer to a confidence level of 95% whereas CIs for η_p^2 refer to a confidence level of 90%.

IAT results

Table 2 summarizes the descriptive results. *D*-scores were significantly larger than zero for the red-green IAT, $t(37) = 6.25$, $p < .001$, $d = 1.01$, $CI = [0.63, 1.42]$, and the red-yellow IAT, $t(37) = 3.48$, $p < .001$, $d = 0.56$, $CI = [0.22, 0.92]$. In contrast, the *D*-score for the green-yellow IAT did not indicate a significant color-validity effect in the hypothesized direction.

To explore the role of IAT order, congruency order, and key mapping order on the observed IAT effects, we additionally ran a 3 (color-IAT) $\times$ 3 (IAT order) $\times$ 2 (congruency order) $\times$ 2 (key-mapping order) mixed ANOVA, with color-IAT as the only within-subjects factor. In cases of violations of the sphericity assumption, we report Greenhouse-Geisser corrected degrees of freedom.

Table 2*Mean (SD) RTs and D-scores for each color-IAT of Experiment 1*

IAT	RTs congruent blocks	RTs incongruent blocks	D-scores
Red-green	766 (369)	852 (484)	.20 (.20)
Red-yellow	775 (410)	821 (427)	.14 (.24)
Green-yellow	820 (443)	814 (445)	-.03 (.24)

Note. Congruent blocks are defined by red-false or green-true response mapping, respectively.

D-scores differed significantly between the three IATs, $F(1.96, 51) = 11.48, p < .001$, $\eta_p^2 = .31$, $CI = [0.13, 0.45]$, indicating variation in effect sizes across color combinations. However, in light of the negative *D*-score for the green-yellow IAT, this effect is not particularly surprising.¹ For this reason, we decided to not include the green-yellow IAT in a planned comparison. Instead, we only compared *D*-scores between the red-green and red-yellow IAT, which did not differ significantly, $F(1, 37) = 1.50, p = .228$, $\eta_p^2 = .04$, $CI = [0.00, 0.18]$. We also observed a significant main effect of congruency order, $F(1, 26) = 17.23, p < .001$, $\eta_p^2 = .40$, $CI = [0.16, 0.58]$, which was based on stronger IAT-effects for participants who completed incongruent IAT-blocks first ($M = .18, SD = .23$) than for those who completed congruent blocks first ($M = .03, SD = .24$). Importantly, this main effect was qualified by a color-IAT by congruency order interaction, $F(1.96, 51) = 4.81, p = .013$, $\eta_p^2 = .16$, $CI = [0.02, 0.30]$. As illustrated in Figure 2, differences between the three color-IATs were more pronounced when congruent IAT blocks preceded the incongruent IAT blocks. Furthermore, there was also a color-IAT by IAT order interaction, $F(3.92, 51) = 2.72, p = .040$, $\eta_p^2 = .17$, $CI = [0.01, 0.32]$. To account for this effect, we ran another ANOVA that only included the first IAT of each participant (i.e., with color-IAT now being a between-subjects factor). The main results of this

¹ Because we had defined congruent and incongruent blocks based on hypothesized effects, not the actual data obtained, negative *D*-scores result whenever the observed IAT effect contradicts the expected effect.

ANOVA were essentially the same as the one for the full data, indicating that the effect of colors did not only occur because of order effects (more detailed results of this supplementary analysis are provided on the OSF: <https://osf.io/78nfc/>). There were no further significant effects or interactions, all $ps > .05$.

Figure 2

Distribution, mean, and standard deviation of participants' IAT D -scores in Experiment 1 by color-IAT and congruency order.

Explicit color-validity associations

When directly asked about their color-validity associations in the questionnaire, 87% indicated that they associated red with falsity, and 71% of the participants indicated that they associated green with truth. A complete list of participants' explicit color associations is provided on the OSF.

Discussion

Taken together, the results of Experiment 1 support our assumption that people show red-false and green-true associations, but that such associations depended on the color context.

More precisely, we only found the hypothesized IAT effect in the red-green and red-yellow IATs, but not in the green- yellow IAT. What is more, color-validity associations were stronger when participants completed incongruent IAT blocks first. However, this congruency-order effect varied across IATs, suggesting that color-validity associations differ in their stability depending on the color-context. While the red-green IAT effect was not affected by congruency order, effects for the other two IATs were not as robust (see Figure 2).

The finding that the green-yellow IAT did not display an effect in the hypothesized direction might suggest that the association between green and true is weaker than that one between red and false. Yet, Nadarevic et al. (2021) observed symmetrical color-validity associations for red and green in the context of each other, and no validity associations for either color when paired with gray. Note, however, that in contrast to the Stroop task used by Nadarevic and colleagues, the IAT indicates relative associations (e.g., the relative strength of green-true vs. yellow-true and green-false vs. yellow-false associations, respectively). As a result, measured associations are highly dependent on the contrasting color. For this reason, we changed the control color from yellow to gray in Experiment 2.

Experiment 2

In Experiment 2, gray served as the control color because it appears to be neutral in the context of color-validity associations (Nadarevic et al., 2021). In addition, we used easy mathematical equations instead of statements as stimuli for the categories *true* and *false* to see if the effects would replicate with these materials.

Methods

Participants

We did not conduct an a-priori power analysis but aimed at collecting as much participants as possible within one week, which was the time during which a laboratory was available for data collection. Ninety-nine participants took part in the experiment, but we excluded the data of one participant who performed poorly on the Ishihara test (60% incorrect

responses). The final sample thus consisted of 98 participants (76 female, 22 male) with a mean age of $M = 22.80$ ($SD = 4.25$) years. Based on this final sample, we conducted the following sensitivity analyses with G*Power. Given a target power of .90 and an α -level of .05, our sample was sufficiently large to reliably detect IAT effects as small as $d = .30$ with one sample t -tests (one-tailed).

Design, Materials, and Procedure

The design and procedure were the same as in Experiment 1, except for the use of different materials. Ten true and ten false simple mathematical equations (e.g., $2 + 5 = 7$) served as IAT stimuli for the validity-categorization trials, and 30 pictures of single-colored objects (red, green, and gray) for the color-categorization trials, which were combined depending on the color-IAT (red-green, red-gray, green-gray).

Results

IAT results

Table 3 summarizes the descriptive results. We again found a significant positive effect for the red-green IAT, $t(97) = 4.99$, $p < .001$, $d = 0.50$, $CI = [0.29, 0.72]$. There was also a significant positive effect for the green-gray IAT, $t(97) = 5.91$, $p < .001$, $d = 0.60$, $CI = [0.38, 0.81]$. For the red-gray IAT, however, the D -score turned out to be negative.

Table 3

Mean (SD) RTs and D-scores for each color-IAT of Experiment 2

IAT	RTs congruent blocks	RTs incongruent blocks	D -scores
Red-green	790 (446)	848 (548)	.13 (.25)
Red-gray	825 (470)	799 (451)	-.08 (.23)
Green-gray	792 (420)	853 (498)	.13 (.22)

Note. Congruent blocks are defined by red-false or green-true response mapping, respectively.

Not surprisingly, a 3 (color-IAT) $\times$ 3 (IAT order) $\times$ 2 (congruency order) $\times$ 2 (key-mapping order) mixed ANOVA with *D*-scores as the dependent variable indicated a significant IAT main effect, $F(2, 171.61) = 26.87, p < .001, \eta_p^2 = .24, CI = [0.15, 0.32]$. A planned comparison between the two IATs with positive *D*-scores (i.e., red-green IAT vs. green-gray IAT), however, did not show any significant differences, $F < 1$. As in Experiment 1, there was also a main effect of congruency order (see Figure 3), $F(1, 86) = 5.64, p = .020, \eta_p^2 = .06, CI = [0.01, 0.16]$, indicating stronger IAT-effects for participants who had completed incongruent IAT-blocks first ($M = .10, SD = .23$) than for those who had completed congruent blocks first ($M = .03, SD = .27$). Furthermore, we found an effect of IAT order, $F(2, 86) = 3.89, p = .024, \eta_p^2 = .08, CI = [0.01, 0.18]$. For this reason, we ran another ANOVA that only included the first IAT per participant (i.e., with color-IAT now being a between-subjects factor). Yet, this analysis replicated the previous results (see supplementary analysis on the OSF: <https://osf.io/n2gyf/>). There were no further main effects or interactions, all $ps > .05$.

Figure 3

Distribution, mean, and standard deviation of participants' IAT *D*-scores in Experiment 2 by color-IAT and congruency order.

Explicit color-validity associations

When directly asked about their color-validity associations, 89% of the participants indicated that they associate red with falsity, and 80% indicated that they associate green with truth. A complete list of participants' explicit color associations is provided on the OSF.

Discussion

In Experiment 2, we found the hypothesized associations in the red-green and green-gray IAT, but not for the red-gray IAT. These results, in combination with the ones of Experiment 1, corroborate the context-dependency of color meaning. While red and green reliably trigger associations to *false* and *true* when presented in the same context, these associations do not necessarily occur in the context of other colors. Additionally, the observed congruency order effects on *D*-scores underline the susceptibility of associations to other contextual factors. Yet, one finding of Experiment 2 that is difficult to reconcile is the negative *D*-score observed for the red-gray IAT, indicating a red-positive rather than a red-negative association in the context of gray (at least descriptively). Possibly, this unexpected result relates to the fact that we did not match colors on lightness and chroma. Indeed, past studies have shown that lighter stimuli are evaluated more positively than darker ones (e.g., Meier et al., 2004) which might have biased our results. For this reason, we matched colors on lightness and chroma in Experiment 3.

Experiment 3

Color stimuli in Experiment 3 were uniformly colored geometrical shapes matched on lightness and chroma. Moreover, we simplified the experimental task by using true- and false-related words as attribute stimuli and by varying the three color-IATs (red-green, red-gray, green-gray) between instead of within participants. Thus, each participant only performed one instead of three IATs which was expected to reduce order and fatigue effects, respectively.

Methods

Participants

An a-priori power-analysis with G*Power suggested a sample size of $N = 108$ participants (i.e., 36 participants per color-IAT) to test each IAT's mean D -score with a one-sample t -test (one-tailed). As in Experiment 1, the input parameters for the power analysis were a target power of .90, a conventional significance level of $\alpha = .05$, and an expected IAT effect of $d = .50$. Participants were recruited via the online-platform SurveyCircle and social media. One-hundred-and-eight people completed the experiment. However, we had to excluded nine participants for the following reasons, some of which were concurrent: color-blindness ($n = 1$), trouble identifying the colors displayed ($n = 1$), and RTs shorter than 300 ms in more than 10% of the trials ($n = 7$). The final sample thus included 102 participants (65 female, 37 male) with a mean age of $M = 27.6$ ($SD = 8.3$) years.

Design, Materials, and Procedure

The experimental design was a 3 (color-IAT: red-green, red-gray, green-gray) $\times$ 2 (block order: congruent vs. incongruent block first) $\times$ 2 (key-mapping order: “true” left vs. “true” right first) between-subject design. Color stimuli were five simple geometrical shapes (circle, triangle, parallelogram, square, diamond) of comparable size that differed in hue but not in lightness or chroma (green: LCh[55.187/82.195/ 136.016], red: LCh[55.187/82.195/40], gray: LCh[55.187/-/ -]). Moreover, we selected five true-related words (e.g., correct, proven) and five false-related words (e.g., faulty, wrong) from Nadarevic et al. (2021) as stimuli for the validity-categorization trials. The procedure was similar to the previous experiments, except for the following changes: Due to the Covid-19 pandemic, we ran the experiment as a web-based study programmed with lab.js (Henninger et al., 2021). Each participant completed only one IAT. Unlike in Experiments 1 and 2, we neither assessed explicit color associations nor administered the Ishihara test. However, we asked participants whether they had full color

vision, whether they could identify all colors in the experiment, and whether they participated seriously.

Results

Table 4 summarizes the descriptive results. Again, D -scores turned out to be significantly positive for the red-green IAT, $t(32) = 6.12$, $p < .001$, $d = 1.07$, $CI = [0.64, 1.51]$, and the green-gray IAT, $t(34) = 3.82$, $p < .001$, $d = 0.65$, $CI = [0.28, 1.02]$. In contrast, the D -score for the red-gray IAT was again negative.

Table 4

Mean (SD) RTs and D-scores for each color-IAT of Experiment 3

IAT	RTs congruent blocks	RTs incongruent blocks	D -scores
Red-green	691 (403)	824 (517)	.34 (.32)
Red-gray	789 (492)	724 (368)	-.10 (.43)
Green-gray	691 (382)	784 (469)	.25 (.40)

Note. Congruent blocks are defined by red-false or green-true response mapping, respectively.

A 3 (color-IAT) $\times 2$ (congruency order) $\times 2$ (key-mapping order) between-subjects ANOVA with D -scores as the dependent variable also showed an IAT main effect, $F(2, 92) = 20.75$, $p < .001$, $\eta_p^2 = .31$, $CI = [0.18, 0.42]$. A planned comparison between the two IATs with positive D -scores (i.e., red-green IAT vs. green-gray IAT), however, did not display a significant difference between the two, $F < 1$. Again, there was a main effect of congruency order, $F(1, 92) = 34.64$, $p < .001$, $\eta_p^2 = .27$, $CI = [0.15, 0.39]$. Unlike in Experiments 1 and 2, however, D -scores tended to be larger when congruent blocks were administered first ($M = .36$, $SD = .35$) than when incongruent blocks were first ($M = -.03$, $SD = .41$). Importantly, this effect was qualified by a color-IAT by congruency order interaction, $F(2, 92) = 5.13$, $p = .008$, $\eta_p^2 = .10$, $CI = [0.02, 0.20]$. While the D -score for the red-green IAT was unaffected by congruency

order, *D*-scores for the other two IATs tended to be smaller when the incongruent blocks came first (see Figure 4). There were no further significant effects or interactions, all $ps > .05$.

Figure 4

Distribution, mean, and standard deviation of participants' IAT *D*-scores in Experiment 3 by color-IAT and congruency order.

Discussion

Although we matched colors on lightness and chroma, and participants performed solely one IAT, the results of Experiment 3 are largely consistent with the results of Experiment 2. That is, *D*-scores were positive only for the red-green IAT and the green-gray IAT, but not for the red-gray IAT. Moreover, once again, congruency order did not affect the red-green IAT effect, but attenuated the effects of the other two IATs, albeit differently than in the previous experiments. To conclude, IAT effects reflecting red-false/green-true associations are reliably observed when red and green appear in the same context. Moreover, in this case, the associations also seem to be robust against procedural influences such as IAT order effects. The pairings of red and green with other colors, on the other hand, seem to be highly susceptible to

procedural variations and may even produce IAT effects that do not point in the expected direction (as in case of the red-gray IAT).

Experiment 4

Experiment 4 aimed to test red-false and green-true associations on a conceptual level, that is, without color visualization. In other words, we tested whether color-validity associations also unfold without color display. Instead of presenting color images as IAT targets, we thus used names of objects (e.g., *tomato*) that are prototypical for a particular color (e.g., red). This time, yellow and gray served as control colors.

Methods

Participants

Based on an a-priori power-analysis with G*Power, we aimed for a sample size of $N = 135$ participants (i.e., 27 participants per color group) to test each IAT's mean D -score with a one-sample t -test (one-tailed). This time, the input parameters for the power analysis were a target power of .80, a conventional significance level of $\alpha = .05$, and an expected IAT effect of $d = .50$. Participants were recruited via the online-platform SurveyCircle and social media. One-hundred-thirty-five participants completed the experiment. However, we excluded the data of four participants for the following reasons: colorblindness ($n = 3$) and more than 10% of trials shorter than 300 ms ($n = 1$). The remaining 135 participants (109 female, 24 male, 2 diverse) had a mean age of $M = 28.3$ ($SD = 13.6$) years.

Design, Materials, and Procedure

The experiment was a 5 (color-IAT: green-red, green-gray, red-gray, red-yellow, green-yellow) $\times$ 2 (block order: congruent vs. incongruent block first) $\times$ 2 (key-mapping order: "true" left vs. "true" right first) between-subjects design. We used the same true- and false-related words as in Experiment 3 but replaced pictures by words as color representatives (e.g., *banana*, *lemon*, *cheese* for yellow, *heart*, *cherry*, *ketchup* for red, ...). We selected five representatives for each color that had been assigned frequently to the respective target color, but not to other

colors in a pretest with $N = 28$ participants. We also made sure that the selected words were comparable across colors in terms of word length and pretested valence ratings. The procedure was identical to Experiment 3.

Results

Prior to analyzing the RT data, we excluded ten individual data points that were characterized by negative RTs due to a software error. Table 5 summarizes the descriptive results. D -scores were significantly positive for the green-gray IAT, $t(25) = 6.09$, $p < .001$, $d = 1.20$, $CI = [0.70, 1.73]$, and the red-yellow IAT, $t(26) = 1.78$, $p = .044$, $d = 0.34$, $CI = [-0.05, 0.74]$, but not for the red-green IAT, $t(26) = 1.06$, $p = .149$, $d = 0.20$, $CI = [-0.18, 0.59]$. Similar to the previous experiments, D -scores for the red-gray IAT and the green-yellow IAT were again negative.

Table 5

Mean (SD) RTs and D-scores for each color-IAT of Experiment 4

IAT	RTs congruent blocks	RTs incongruent blocks	D -scores
Red-green	745 (349)	785 (377)	.11 (.53)
Red-gray	937 (500)	749 (385)	-.52 (.38)
Red-yellow	744 (351)	797 (418)	.16 (.47)
Green-gray	753 (323)	952 (476)	.51 (.43)
Green-yellow	878 (572)	764 (369)	-.34 (.46)

Note. Congruent blocks are defined by red-false or green-true response mapping, respectively.

A 5 (color-IAT) $\times 2$ (congruency order) $\times 2$ (key-mapping order) between-subjects ANOVA confirmed a main effect of color-IAT on D -scores, $F(4, 119) = 19.56$, $p < .001$, $\eta_p^2 = .40$, $CI = [0.28, 0.48]$. Importantly, however, the effect was again qualified by an interaction with congruency order, $F(4, 119) = 10.51$, $p < .001$, $\eta_p^2 = .26$, $CI = [0.14, 0.35]$. As illustrated

by Figure 5, the pattern of IAT effects varied considerably depending on congruency order. There were no further significant main effects or interactions, all $ps > .05$.

Figure 5

Distribution, mean, and standard deviation of participants' IAT D -scores in Experiment 4 by color-IAT and congruency order.

Discussion

The use of conceptual color representatives in Experiment 4 led to some partly unexpected results. Only the green-gray IAT and the red-yellow IAT showed a significant positive D -score. For all other color-IATs, effects were either not significant or negative, that is, in the opposite direction to our prediction. Moreover, IAT effects were strongly affected by

congruency order, and *D*-scores showed a great variability across participants (see Table 4 and Figure 5). Taken together, the results suggest that there are no stable color-validity associations on the conceptual level. In other words, activating color-validity associations by the use of concepts associated with those colors is not possible in the same way as it is by the use of a visual display of colors.

Summary of Experiments 1 to 4

Experiments 1 to 4 measured color-validity associations with IATs involving different target colors and materials. As predicted, red-green IATs reliably displayed red-false/green-true associations. However, this IAT effect did not replicate when the IAT did not involve any colored stimuli but represented colors on the conceptual level (see Experiment 4). What is more, IATs contrasting one of the target colors (red or green) with a control color (gray or yellow) largely failed to find stable red-false or green-true associations. Similarly, the red-green IAT also proved to be much more robust against congruency order effects than IATs testing validity-associations for other color combinations.

Taken together, our results confirm that color contexts play a crucial role for color-validity associations. Furthermore, they speak in favor of robust red-false/green-true associations in a context involving both colors. What is unclear, however, is how to account for the results of the IATs comparing red or green to gray or yellow, respectively. For example, we consistently found negative *D*-scores for red-gray IATs although participants' explicit color associations clearly argue against an association between gray and false (or red and true, respectively). Likewise, no gray-false/red-true effects were found in the Stroop experiments of Nadarevic et al. (2021). Hence, it is questionable whether the reported IAT results truly reflect color-validity associations. Building on studies that have outlined methodological problems of the IAT, a final, registered experiment aims to test whether color-validity IAT effects are biased by color-valence associations and/or saliency asymmetries.

Registered Experiment

According to Greenwald et al. (2005), the IAT measures associations by reflecting the mental compatibility of nominal features of the named target and attribute categories. Yet there is empirical evidence that participants may recode the target categorization task and the attribute categorization task into a single task that is based on a common feature (Meissner & Rothermund, 2015; Rothermund et al., 2009). Although this feature can be a nominal one, e.g., valence in the classical flower-insects IAT (Greenwald et al., 1998), this does not have to be the case. For example, in an IAT study by De Houwer et al. (2005), participants were faster to categorize pictures of pizzas and coins with one key and pictures of snakes and rivers with the other key than when the pairings were reversed. This finding suggests that participants recoded the IAT task based on the common feature “shape”. Hence, instead of reflecting semantic associations, this IAT effect likely reflected perceptual similarities of the IAT categories.

Another confounding feature that has been discussed in the IAT literature is salience. Rothermund and Wentura (2004) showed that responses are faster when salient categories from target and attribute dimensions are mapped onto the same response key than when they are mapped on different keys. In order to identify the contribution of salience in an IAT effect the authors suggested the use of a word-nonword IAT to accompany the standard IAT. They predicted faster RTs when nonwords are paired with the salient compared to the non-salient target category because nonwords “are highly unfamiliar and should pop out of against a background of common neutral words” (Rothermund & Wentura, 2004, p. 142). Thus, if an IAT effect is purely based on salience asymmetries, effect sizes of the word-nonword IAT and the IAT effect of interest should not differ substantially. Additionally, Rothermund and Wentura (2004) were even able to reverse the established IAT effect of associating old and bad as well as young and good by manipulating stimulus salience independently by means of a previous Go/No-go task. However, IAT effects were still larger when the salience manipulation was consistent with the default association, indicating that salience is still not the only factor

contributing to IAT effects. In a similar vein, results by Kinoshita and Peek-O'Leary (2006) indicate that IAT effects can be driven by both: salience asymmetries and evaluative associations. Besides salience, valence thus often plays a role when participants try to find a common feature of attribute and target dimension. While this is absolutely intended when measuring purely affective associations, this might not be the case when we choose an attribute dimension that goes beyond pure valence such as “validity”.

Research Goal

The goal of the experiment is to assess the contribution of valence effects and salience-asymmetries in color-validity IATs. For this reason, we will compare the *D*-scores of three different types of IATs: 1) color-validity IATs, 2) color-valence IATs (see Schietecat et al., 2018b), and 3) color-nonword/word IATs (see Rothermund and Wentura, 2004). Importantly, we will examine these IAT effects across two different sets of colors. One set will contrast red and green as our primary colors of interest. The other set will contrast yellow and gray as two presumably unrelated colors to the validity dimension. We predict that the contribution of valence effects and salience asymmetries in color-validity IAT scores will be smaller when the color context highlights validity as the nominal feature (i.e., in the red-green context) than when it does not (i.e., in the yellow-gray context). In other words, we assume that IAT effects for the red/green-validity IAT reflect, at least to some degree, real color-validity associations. In contrast, IAT effects for the yellow/gray-validity IAT are expected to rely on other causes. More concrete hypotheses are outlined below. Even though further color-combinations in line with our previous experiments would be interesting as well, they are not feasible due to the required sample size (see power-analysis below). Nevertheless, we hope that the results of the yellow-gray IATs will give us clues as how to interpret the findings of the color-IATs in the previous experiments.

Hypotheses

Red-green IATs

The association of red with mostly negative concepts, like failure (Elliot et al., 2007), anger (Fetterman et al., 2012), or loss (Kliger & Gilad, 2012) suggests that red is evaluated more negatively compared to green, which in turn is mainly associated with positive concepts such as success (Hong et al., 2020) or creativity (Lichtenfeld et al., 2012). Indeed, Schietecat et al. (2018b) observed IAT effects reflecting a red-negative/green-positive association in a red/green-valence IAT. Because the attributes true and false also carry positive and negative connotations, respectively, color-valence associations might generally contribute to color-validity effects. Yet, we believe that red-false and green-true associations exist, that is, that they are not entirely due to valence asymmetries of red and green. Thus, we predict the *D*-score of a red/green-validity IAT (indicating red-false/green-true associations) to be significantly larger than the *D*-score of a red/green-valence IAT (indicating red-negative/green-positive associations). Regarding salience-asymmetries, it is more difficult to derive clear predictions for a red-green IAT. While an EEG study by Xia et al. (2018) demonstrated that red captures more early attention than green in a modified dot-probe task, Wool et al. (2015) did not find any differences in salience for red and green when using a visual search task. However, one might argue that the association of red with danger (Pravossoudovitch et al., 2014) is a sign of red being more salient than green. Thus, if we do find a red/green-saliency IAT effect, red should be more salient than green. More importantly, however, we expect this salience effect (if present) to be significantly smaller than the red/green-validity effect and the red/green-valence effect (as measured by *D*-scores).

Gray-yellow IATs

Given the assumption that salience effects and valence effects will be more pronounced in IATs involving colors unrelated to the validity dimension, the question emerges which feature might drive such effects. Due to the particularly surprising effects for the IATs involving

gray, we believe that chroma might be such a feature. For example, comparing chromatic and achromatic colors, Wilms and Oberfeld (2018) found that chromatic colors are not only evaluated as more pleasant than achromatic ones but also that the sight of them causes an acceleration of the heart rate while achromatic colors cause deceleration. Additionally, Wang and Ding (2012) reported a positive correlation between chroma and participants' valence and arousal ratings. In a direct comparison with chromatic colors, gray is thus potentially evaluated as more negative than chromatic colors. For this reason, we predict to find the *D*-score of a yellow/gray-valence IAT to indicate yellow-positive/gray-negative associations. Additionally, one might take more arousal caused by chromatic colors as a sign of chromatic colors being more salient than achromatic ones. Thus, if we do find a yellow/gray-saliency IAT effect, we expect yellow to be more salient than gray. To conclude, we predict that yellow will show to be more positive and more salient than gray. In contrast, we do not expect yellow and gray to be associated with validity. For this reason, we expect the yellow/gray-validity IAT effect to be smaller than the valence- and salience IAT effects for the colors yellow and gray. Regarding the latter two IATs, we do not set up a specific prediction with regard to their relative sizes.

Methods

Participants

In order to determine the sample size required to test our main hypotheses (i.e., the expected main effect of IAT type for the green-red IAT and the yellow-gray IAT effect, respectively), we conducted an a-priori power analysis with G*Power with the following input parameters: Target power $1-\beta = .95$, conventional significance level $\alpha = .05$, minimum effect size of interest $f = .15$. This analysis suggested a target sample size of $N = 690$ participants. However, based on an anticipated data exclusion rate of 5%, we plan to recruit $N = 725$ participants. We will collect data online via the platform "prolific". Only participants who fulfill the following criteria will be eligible to participate: German nationality, age between 18 and 50 years, and full color vision.

Design

The experiment will have a 2 (color-IAT: green-red, yellow-gray) $\times$ 3 (IAT type: validity, valence, salience) $\times$ 2 (IAT order: green-red first vs. yellow-gray first) $\times$ 2 (block order: congruent vs. incongruent block first) $\times$ 2 (key-mapping order: truth/salience/positivity left vs. truth/salience/positivity right first) mixed design with color-IAT being the only within-subject factor. Participants' *D*-Scores will serve as the dependent variable.

Materials and Procedure

As in Experiment 2, we will use geometrical shapes as color stimuli. More precisely, we will display five geometrical shapes varying in hue, but matched on lightness and chroma within the green-red IAT (green: LCh[55.187/ 82.195/ 136.016], red: LCh[55.187/ 82.195/ 40]) and the yellow-gray IAT (yellow: LCh[79.881/ 86.681/ 102.280], gray: LCh[79.881/ – / –]). For the validity IAT, we will again use the five true-related and five false-related words from previous experiments as attribute stimuli. In addition, we will use five pleasant and five unpleasant words from Rothermund and Wentura (2004) for the valence IAT, and five neutral words and five nonwords of the same authors for the word-nonword IAT. A list of all stimuli is provided on the OSF (<https://osf.io/s6xu2/>). The general IAT procedure will be identical to previous experiments, except for the attribute dimension on which stimuli have to be categorized. Specifically, participants will categorize stimuli in the validity IAT as true vs. false, in the valence IAT as positive vs. negative, and in the salience IAT as words vs. nonwords.

Data Analysis and Results

The data analysis will follow the analyses of the previous experiments (i.e., exclusion criteria, *D*-score calculation). In a first step, we will test participants' *D*-scores for each combination of color-IAT and IAT type with one-sample *t*-tests (two-tailed). Furthermore, we will conduct a 2 (color-IAT) $\times$ 3 (IAT type) $\times$ 2 (IAT order) $\times$ 2 (block order) $\times$ 2 (key mapping order) mixed ANOVA on participants' *D*-scores with all factors but color-IAT varying between participants. Irrespective of whether we find a color-IAT by IAT type interaction, we will test

our main hypotheses be means of two planned comparisons. First, we will test for a stronger validity than valence and salience effect in IATs contrasting red and green. Second, we will test for a weaker validity than valence or salience effect for the yellow-gray IAT. We will report effect sizes as Cohen's d for t -tests and η_p^2 for the ANOVA.

Discussion

[will be added after data collection]

General Discussion

[will be added after data collection]

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