

Immediate Effects of Color Vision Fatigue and Semantic Satiation on Color Categorical Perception: Postprint

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Abstract

Whether color categorical perception is linguistic or perceptual in nature, or arises from cognitive conflicts due to their interaction, remains a subject of investigation and debate. This study employed color vision fatigue and semantic satiation manipulations to independently alter perceptual or semantic processing, observing the immediate effects of both on color categorical perception effects, in order to investigate the roles of language and perception in color categorization. Results showed that the color vision fatigue manipulation led to decreased reaction times for between-category color discrimination, enhancing the color categorical effect. The semantic satiation manipulation resulted in increased reaction times for within-category color discrimination for colors belonging to the saturated color word category, enhancing the color categorical effect. These findings demonstrate that independently altering either perceptual or semantic processing capabilities can influence CCP effects, supporting the linguistic label contrast model, which posits that the interaction between language and perception gives rise to color categorical perception.

Full Text

Categorical Perception of Color Can Be Instantly Influenced by Color Vision Fatigue and Semantic Satiation

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Abstract

Whether categorical perception of color (CCP) is fundamentally perceptual, linguistic, or arises from cognitive conflict between the two remains an active area of investigation and debate. The present study independently manipulated perceptual and semantic processing through color vision fatigue and semantic satiation procedures to observe their immediate effects on CCP. Results showed that color vision fatigue reduced reaction times for between-category color discrimination, thereby enhancing the CCP effect. Semantic satiation increased reaction times for within-category color discrimination involving the satiated color term, also strengthening CCP. These findings demonstrate that altering either perceptual or semantic processing alone can influence CCP, supporting the verbal label comparisons model—namely, that CCP arises from the interaction between language and perception.

Keywords: categorical perception of color; color vision fatigue; semantic satiation; linguistic universalism; linguistic relativism

Introduction

Categorical perception of color (CCP) refers to the phenomenon where discrimination of within-category (WC) colors (colors sharing the same color name) is slower or less accurate than discrimination of between-category (BC) colors (colors from different categories). The CCP effect persists even after controlling for perceptual differences between color stimuli (Witzel & Gegenfurtner, 2016), suggesting that additional factors influence color perception.

Numerous studies have found that language can affect CCP. Cross-linguistic research reveals that speakers of different languages exhibit different CCP effects (He, Li, Zhang, & Zhang, 2016; Winawer et al., 2007), and the CCP effect is stronger in the right visual field than in the left (Drivonikou et al., 2007; Gilbert, Regier, Kay, & Ivry, 2006; Zhong, Li, Huang, Li, & Mo, 2017). Neuroimaging studies show greater activation differences in the left hemisphere during between- versus within-category discrimination (Liu et al., 2009; Mo, Xu, Kay, & Tan, 2011). Gilbert et al. (2006) proposed that the left hemisphere, which processes right visual field information and is typically language-dominant in right-handers, shows stronger CCP effects due to greater language influence. However, research also demonstrates that pre-linguistic infants and primates exhibit color categories (Franklin et al., 2008a; Franklin et al., 2005; Skelton, Catchpole, Abbott, Bosten, & Franklin, 2017; Tajima et al., 2016; Yang, Kanazawa, Yamaguchi, & Kuriki, 2016), with infants showing stronger CCP effects in the left visual field (Franklin et al., 2008a; Franklin et al., 2008b). These findings indicate that perceptual processing also contributes to CCP.

Given substantial evidence for both perceptual and linguistic influences, neither can be completely dismissed. Consequently, recent theoretical efforts have

shifted toward integrative or compromise models that accommodate both perspectives (Zhang, Fang, & Xie, 2012). The categorical/verbal label comparisons model (VLC) represents a prominent integrative framework that explicitly explains how language and perception interact to produce CCP (Roberson & Hanley, 2010). According to this model, when the perceptual system processes a color stimulus, visual/perceptual encoding is first represented, followed rapidly by corresponding verbal/categorical encoding. An automatic comparator then unconsciously discriminates color similarities and differences, with cognitive control ultimately selecting between the two encoding outcomes. For between-category discrimination, both visual and linguistic encodings signal “different,” creating no conflict. For within-category discrimination, however, visual encoding signals “different” while linguistic encoding signals “same,” generating cognitive conflict that increases reaction times (Hu, Hanley, Zhang, Liu, & Roberson, 2014). The VLC model thus posits independent contributions from language and perception, with CCP arising not from either system alone but from conflict between categorical color codes and perceptual encoding results.

Previous research has primarily used participant characteristics—such as language differences (e.g., Russian vs. English speakers) or language usage differences (e.g., infants vs. adults)—as independent variables, assuming these characteristics can separate linguistic from perceptual influences on CCP. However, participants from different language backgrounds or developmental stages also differ in life experiences and color exposure, introducing non-linguistic variance that compromises the reliability of linguistic effects. Although electrophysiological and neuroimaging methods partially address this issue, they cannot experimentally manipulate established CCP effects, limiting researchers to post-hoc explanations rather than experimental control. While some studies have experimentally manipulated language processing (Liu et al., 2008; Zhong et al., 2014; Gilbert et al., 2006), few have directly manipulated color perception experimentally.

The VLC model suggests that perceptual and linguistic systems independently encode color information, with their interaction in cognitive control producing CCP. This implies that experimentally manipulating either perceptual or linguistic processing alone should reveal how each system contributes to CCP, providing a stronger test of the VLC model. The present study employed experimental, immediate, and separable manipulations of participants’ color vision and semantic processing to examine changes in CCP. Experiment 1 used color vision fatigue to disrupt perceptual processing and explore its impact on CCP. Experiment 2 used semantic satiation to disrupt semantic processing of specific color terms and examine its effects on CCP.

This study involved three experimental tasks: visual search, color vision fatigue, and semantic satiation. The visual search task, commonly used in CCP research, requires participants to identify a unique color chip (target) among 12 chips surrounding a central fixation point. When the background and target colors belong to the same category, this constitutes within-category discrimina-

tion; when they belong to different categories, it constitutes between-category discrimination.

Color vision is fundamental to color perception. Color vision fatigue occurs when prolonged fixation on a colored target produces an afterimage that gradually obscures the original stimulus until it becomes nearly invisible. Research shows that flickering colored light can induce color vision fatigue (Li, 1995). Cogan and Cogan (1938) defined color vision fatigue as abnormal perception of colored light, with its duration equaling that of the afterimage produced after viewing colored light. Their research demonstrated that after 15 seconds of red light fixation, a visual afterimage lasting 14-18 seconds appeared in a 10° gray field. The present study used rapid alternation between two colors from the same category as a fatigue stimulus to disrupt color vision processing. We predicted that color vision fatigue would impair perceptual encoding, reducing its contribution to the visual search task while relatively increasing the role of semantic encoding. This should slow within-category discrimination and speed between-category discrimination, thereby enhancing CCP.

Semantic satiation provides an effective method for disrupting semantic processing. Repeated processing of a word slows subsequent semantic judgments involving that word. This phenomenon occurs with Chinese characters (Cheng & Lai, 2012; Yuan et al., 2016) and reflects a linguistic rather than perceptual phenomenon (Lewis & Ellis, 2000; Galmar, 2012). The present study used frequent semantic judgment tasks to slow processing of satiated words (Jakobovits & Lambert, 1961) and thereby disrupt semantic processing.

Notably, previous language manipulation studies used secondary tasks that prevented participants from utilizing overall language function during color discrimination (Gilbert et al., 2006; Liu et al., 2008). In contrast, semantic satiation only disrupts processing of a specific color term without affecting other linguistic functions. Therefore, semantic satiation may influence CCP differently than previous methods. We predicted that semantic satiation would interfere with semantic encoding of the satiated word, making its retrieval more difficult.

Experiment 1: Effects of Color Vision Fatigue on CCP

Purpose

To investigate how color vision fatigue, which disrupts color perception, influences CCP.

Participants

Thirty university students (8 male, 22 female) aged 18-23 years ($M = 21$, $SD = 1.37$) participated. All were right-handed with normal or corrected-to-normal vision, no color blindness or weakness, and no prior participation in similar experiments. Participants first named six color chips, each presented six times

(36 trials), with a maximum of one error allowed. Twenty-seven participants meeting this criterion completed the formal experiment.

Stimuli and Apparatus

Stimuli were presented on a 17-inch monitor with a 75 Hz refresh rate. The fatigue manipulation used two shades each from green, blue, and purple categories plus gray as backgrounds, with RGB values: (129, 198, 153), (63, 119, 94), (61, 120, 134), (135, 182, 227), (120, 98, 135), (181, 155, 226), and (178, 178, 178). Three figures (circles or triangles) of 0.45° visual angle appeared horizontally on the background. When the background was a dark color, the figures were a light color from the same category, and vice versa. On gray backgrounds, figures were black (RGB: 0, 0, 0).

The visual search task used two color values each from green, blue, and purple categories, presented as 3.5 cm squares with RGB values: G1 (120, 171, 143), G2 (120, 171, 165), B1 (120, 171, 186), B2 (125, 153, 187), P1 (147, 140, 187), and P2 (148, 120, 188). CIE-*Luv** distances were: G1-G2: 17.1, G2-B1: 17.3, B1-B2: 17.4, B2-P1: 17.3, P1-P2: 17.4, with equal average CIE distances for between- and within-category pairs (17.3 vs. 17.3). Different colors were used for the fatigue manipulation and visual search task to increase background-figure contrast during fatigue, facilitating figure recognition and ensuring sustained color stimulation.

Design

A 2 (visual field: left vs. right) \times 2 (fatigue level: fatigued vs. non-fatigued) \times 2 (category type: within-category vs. between-category) within-subjects design was employed. Visual field referred to the location of the different color chip in the visual search task, with left of fixation as left visual field (LVF) and right as right visual field (RVF). Fatigue level referred to whether the background flickered with color. In the fatigued condition (F), two colors from the same category alternated at 50 Hz. In the non-fatigued condition, a constant gray background served as baseline. Category type referred to the relationship between the two colors: within-category (WC) when both belonged to the same category, and between-category (BC) when they belonged to different categories.

To avoid excessive fatigue, each participant underwent fatigue manipulation for only two color categories, balanced across participants (18 sessions per fatigue category). Fatigued and non-fatigued conditions each occurred four times in random order, with 12 visual search trials following each manipulation (8 WC, 4 BC), totaling 96 trials. After green fatigue, visual search color pairs were G1-G2, B1-B2, and G2-B1; after purple fatigue: B1-B2, P1-P2, B2-P1; after blue fatigue: half the participants saw G1-G2, B1-B2, G2-B1 and half saw B1-B2, P1-P2, B2-P1. Non-fatigued conditions were similarly divided.

Procedure

Before the formal experiment, participants completed four practice trials with yellow chips to familiarize themselves with the procedure. Participants sat 90 cm from the screen, with color chips positioned 4.5° from central fixation. During fatigue manipulation, participants judged which side's figure matched the central figure, pressing "q" for left and "p" for right. They were informed they must achieve sufficient accuracy to proceed, ensuring attention to the screen for fatigue induction. After completing the fatigue task, a warning message ("Visual search task starting soon") appeared for 800 ms, followed by a 1000 ms fixation cross, then the visual search task. Participants identified the unique color chip among 12 surrounding a central "+" fixation, pressing "f" if it appeared left and "j" if right. Color chips were presented for 200 ms, with responses required within 1800 ms. Chips only appeared in the two farthest positions from fixation on each side [Figure 1: see original paper]. After fatigue manipulation, participants rested until they reported no eye discomfort and no colored afterimages on the gray screen.

Results and Analysis

Data from one participant with accuracy below 90% were excluded, leaving 26 participants. Errors and outliers beyond 2 SD were removed (approximately 9% of data). Reaction time data are presented in Table 1.

A three-way repeated measures ANOVA on accuracy revealed significant main effects of visual field, $F(1, 25) = 7.46$, $p = 0.011$, $\eta^2p = 0.230$, with lower accuracy in LVF (0.95) than RVF (0.98), and category, $F(1, 25) = 14.91$, $p = 0.010$, $\eta^2p = 0.374$, with lower accuracy for WC (0.95) than BC (0.98). No other effects were significant ($F < 3.79$, $p > 0.063$).

A three-way repeated measures ANOVA on reaction times showed significant main effects of visual field, $F(1, 25) = 5.19$, $p = 0.032$, $\eta^2p = 0.172$, with slower responses in LVF (306 ms) than RVF (293 ms), and category, $F(1, 25) = 49.25$, $p < 0.001$, $\eta^2p = 0.663$. The category \times fatigue level interaction was significant, $F(1, 25) = 49.25$, $p < 0.001$, $\eta^2p = 0.663$. Simple effects analysis revealed that WC discrimination was slower in the fatigued condition (318 ms) than non-fatigued (307 ms), though not significantly, $F(1, 25) = 1.50$, $p = 0.233$. BC discrimination was significantly faster in the fatigued condition (277 ms) than non-fatigued (294 ms), $F(1, 25) = 6.76$, $p = 0.015$, $\eta^2p = 0.213$. No other effects were significant ($F < 1.59$, $p > 0.219$) [Figure 2: see original paper].

Following Gilbert et al. (2006), we analyzed CCP effect magnitude (WC RT minus BC RT) with a two-way repeated measures ANOVA (category \times fatigue level). The main effect of fatigue level was significant, $F(1, 25) = 13.18$, $p = 0.001$, $\eta^2p = 0.345$, with stronger CCP effects in the fatigued condition (41 ms) than non-fatigued (17 ms). No other effects were significant ($F < 0.21$, $p > 0.648$).

Since each fatigue manipulation was followed by visual search trials containing two types of WC pairs—one matching the fatigued category and one not—we further compared “consistent” (WC pair from same category as fatigue stimulus) versus “inconsistent” (WC pair from different category) conditions. Separate two-way ANOVAs (visual field \times category type: consistent-WC vs. inconsistent-WC) for each fatigue level revealed that in the fatigued condition, the visual field main effect was significant for accuracy, $F(1, 25) = 6.09$, $p = 0.022$, $\eta^2 p = 0.194$, with lower accuracy in LVF (0.92) than RVF (0.96), and marginally significant for RT, $F(1, 25) = 3.98$, $p = 0.057$, $\eta^2 p = 0.137$, with slower responses in LVF (328 ms) than RVF (307 ms). No other effects were significant (accuracy: $F(1, 25) < 2.10$, $p > 0.160$; RT: $F(1, 25) < 3.42$, $p > 0.076$).

To rule out effects of specific color categories used in fatigue stimuli, a four-way ANOVA including fatigue color type (green, blue, purple) showed no significant four-way interaction (RT: $F(4, 98) = 0.69$, $p = 0.603$; accuracy: $F(4, 98) = 0.19$, $p = 0.945$), confirming that fatigue stimulus color did not influence results.

Discussion

Experiment 1 used color flicker to induce color vision fatigue and examined changes in CCP. Results showed that BC discrimination was significantly faster in the fatigued condition, while WC discrimination was slower (though not significantly), leading to enhanced CCP effects. This suggests that fatigue disrupted perceptual encoding, relatively increasing the contribution of semantic encoding and thereby strengthening CCP. However, since WC discrimination always involves colors with identical semantics, participants ultimately relied on perceptual information. Thus, even when perceptual processing was impaired, semantic information could not fully compensate, which may explain why WC differences were not significant.

These results indicate that perceptual information processing occurs in the cognitive mechanisms underlying CCP, and that normal adult perceptual processing ability suppresses CCP. They also suggest that semantic processing occurs during visual search, with semantic information facilitating BC discrimination while hindering WC discrimination. Consequently, increased reliance on semantic information strengthens CCP. To further test the role of semantic processing, Experiment 2 used semantic satiation to disrupt semantic processing.

Experiment 2: Effects of Semantic Satiation on CCP

Purpose

To examine the role of color terms in CCP using semantic satiation.

Participants

Thirty university students (same criteria as Experiment 1) participated. After screening for color naming accuracy (maximum one error across 36 trials), 27

participants entered the formal experiment.

Stimuli and Apparatus

Semantic satiation materials consisted of 5.5 cm square two-character Chinese words presented centrally. Three color terms (green, blue, purple), three expression terms (facial expression, eye expression, demeanor), and three plant terms (green tea, blueberry, wisteria) were used. Plant and expression terms served as filler stimuli to prevent participants from responding based on single characters rather than complete word meanings. Each color term appeared in two fonts (Song and Fangsong) to prevent perceptual fatigue from repeated identical characters, which could affect visually presented semantic judgment tasks without influencing conceptual-level semantic processing. Other apparatus was identical to Experiment 1.

Design

A 2 (visual field: left vs. right) \times 2 (satiation level: high vs. low) \times 2 (category type: within-category vs. between-category) within-subjects design was employed. Visual field and category variables were identical to Experiment 1. Satiation level was manipulated by varying the frequency of color words versus expression words. In the high-satiation condition, participants judged 60 color words and 6 non-color words (deviants). In the low-satiation condition, they judged 60 expression words and 6 color words (deviants). Each condition occurred 12 times randomly. Each color term (green, blue, purple) and expression term was satiated four times; plant terms served only as fillers. After satiation, participants completed 12 visual search trials. Each participant completed 288 trials total.

Procedure

Participants first verified their understanding of experimental words (2 judgments per word, 36 trials total). After reading instructions and completing four practice trials, they began the formal experiment. During satiation, participants judged whether each word referred to a color or an expression/plant, pressing “q” for color and “p” for expression/plant. Each word was followed by a 150 ms interval. Participants were informed they must achieve sufficient accuracy to proceed, ensuring semantic processing and satiation. Sixty target words and 6 deviant words were presented, with one deviant randomly appearing among every 7 stimuli (none in the final 12). After satiation, participants completed 12 visual search trials identical to Experiment 1 [Figure 3: see original paper]. Participants rested between tasks.

Results and Analysis

Data from one participant with effective data rate below 80% were excluded, leaving 21 participants. Errors and outliers beyond 2 SD were removed (approx-

imately 5% of data). Reaction time data are presented in Table 2 .

A three-way repeated measures ANOVA on accuracy showed a significant main effect of category, $F(1, 20) = 20.94$, $p < 0.001$, $\eta^2_p = 0.511$, with lower accuracy for WC (0.97) than BC (0.99). The visual field \times category interaction was significant, $F(1, 20) = 4.61$, $p = 0.044$, $\eta^2_p = 0.187$, though simple effects were not significant ($p > 0.079$, $\eta^2_p < 0.146$). No other effects were significant ($F(1, 20) < 1.97$, $p > 0.180$).

A three-way repeated measures ANOVA on reaction times revealed significant main effects of visual field, $F(1, 20) = 6.22$, $p = 0.022$, $\eta^2_p = 0.237$, with slower responses in LVF (279 ms) than RVF (268 ms), and category, $F(1, 20) = 69.36$, $p < 0.001$, $\eta^2_p = 0.776$, with slower responses for WC (285 ms) than BC (262 ms). No other effects were significant ($F(1, 20) < 1.54$, $p > 0.229$).

Because semantic satiation only affects processing of the satiated word, the two WC conditions may be differentially affected. We therefore divided WC trials into “identical-WC” (colors belonging to the satiated word’s category) and “nonidentical-WC” (colors from a different category). Separate two-way ANOVAs (visual field \times category type: identical vs. nonidentical) for each satiation level revealed no significant effects in the low-satiation condition (accuracy: $F(1, 20) < 3.64$, $p > 0.071$; RT: $F(1, 20) < 3.13$, $p > 0.092$). In the high-satiation condition, the category main effect for RT was significant, $F(1, 20) = 10.82$, $p = 0.004$, $\eta^2_p = 0.351$, with slower responses for identical-WC (291 ms) than nonidentical-WC (279 ms). No other effects were significant ($F(1, 20) < 3.20$, $p > 0.089$).

Given this differential effect, Experiment 2 data were analyzed using three category types: identical-WC (Y-WC), nonidentical-WC (N-WC), and BC . A three-way repeated measures ANOVA on RT showed significant main effects of visual field, $F(1, 20) = 5.67$, $p = 0.027$, $\eta^2_p = 0.221$, with slower responses in LVF (283 ms) than RVF (272 ms), and category, $F(1, 20) = 33.65$, $p < 0.001$, $\eta^2_p = 0.780$. The category \times satiation level interaction was significant, $F(1, 20) = 4.67$, $p = 0.022$, $\eta^2_p = 0.330$. Simple effects analysis revealed that in the low-satiation condition, Y-WC (287 ms) and N-WC (283 ms) did not differ significantly ($p = 0.38$), but both were slower than BC (263 ms, $p < 0.001$). In the high-satiation condition, Y-WC (291 ms) was significantly slower than both N-WC (279 ms, $p = 0.004$) and BC (261 ms, $p < 0.001$), and N-WC was slower than BC ($p < 0.001$). No other effects were significant ($F < 0.88$, $p > 0.431$) [Figure 4: see original paper].

We calculated two CCP effect magnitudes: identical-CCP (Y-WC minus BC) and nonidentical-CCP (N-WC minus BC). A three-way repeated measures ANOVA (visual field \times identical type \times satiation level) on CCP effects revealed a significant main effect of identical type, $F(1, 20) = 4.41$, $p = 0.049$, $\eta^2_p = 0.181$, and a significant identical type \times satiation level interaction, $F(1, 20) = 8.47$, $p = 0.009$, $\eta^2_p = 0.298$. Simple effects analysis showed that in the high-satiation condition, identical-CCP (30 ms) was stronger than

nonidentical-CCP (18 ms), $F(1, 20) = 10.77$, $p = 0.004$, $\eta^2_p = 0.350$, but this difference was not significant in the low-satiation condition (23 ms vs. 19 ms), $F(1, 20) = 0.77$, $p = 0.390$. No other effects were significant ($F(1, 20) < 1.48$, $p > 0.239$).

Discussion

Experiment 2's RT data showed that identical-WC responses slowed under high satiation, indicating that participants used semantic information to perform the task. However, these results differ from Gilbert et al. (2006), possibly due to differences between semantic satiation and previous semantic interference tasks.

Gilbert et al. (2006) used an 8-digit memory task and single color word recognition to interfere with language processing, finding reversed CCP effects in the right visual field with both BC and WC discrimination changing in directions that weakened CCP. Liu et al. (2008) replicated this with meaningless two-character words but found no CCP interference or lateralization. Although these studies differed in results, both used secondary tasks to occupy semantic function, preventing participants from using semantic information during visual search. Semantic satiation, however, does not occupy semantic function during visual search but instead requires extensive semantic processing beforehand. Thus, while satiation disrupted semantic processing of the satiated word, it did not inhibit use of semantic function during the task. Consequently, retrieval difficulty for the satiated color word in the identical-WC condition slowed responses.

Experiment 3: Validation of Manipulation Effects on Semantic Processing

Purpose

To verify whether fatigue and satiation manipulations actually changed participants' semantic processing ability.

Participants

Thirty university students (4 male, 26 female) aged 19-24 years ($M = 20.2$, $SD = 1.42$) participated. After rating word-picture matching, 24 participants were randomly assigned to Experiments 3a and 3b.

Stimuli and Apparatus

The visual search task was replaced with a semantic judgment task following fatigue/satiation. Each of three color terms had four exemplars, matched with four black/white tone words, creating 24 exemplar words: green (grassland, tender leaf, celery, kiwi); blue (South China Sea, earth, sky, Pacific Ocean); purple (eggplant, grape, onion, lavender); black/white tone (wood ear mushroom, coal,

ice and snow, rice, salt, soy sauce, saccharin, pure milk, sesame, flour, ant, mature vinegar). Other stimuli were identical to Experiments 1 and 2.

Design

Experiments 3a (fatigue + semantic judgment) and 3b (satiation + semantic judgment) both used a 2 (fatigue/satiation level: high vs. low) \times 2 (match: matched vs. mismatched) \times 2 (delay: 2 s vs. 11+ s) within-subjects design. Fatigue and satiation levels were identical to Experiments 1 and 2. Match referred to whether the exemplar's color matched the category word's meaning. Each color term had four matched exemplars and four black/white mismatched exemplars. Delay was the interval between fatigue/satiation and semantic judgment. Each condition included six trials (48 total), with each word appearing once per fatigue/satiation condition. Exemplar order and response keys were counterbalanced.

Procedure

After fatigue/satiation, a 1000 ms fixation cross appeared, followed by a category word above fixation for 1000 ms, then an exemplar word below fixation. Participants judged whether the exemplar's color belonged to the category word, pressing "f" for match and "j" for mismatch (counterbalanced). After an 8000 ms blank screen and 500 ms asterisk, a second semantic judgment occurred, followed by new fatigue/satiation.

Results and Analysis

Following standard semantic satiation procedures (Tian & Huber, 2010, 2013; Yuan et al., 2016; Zhang, Liu, & Wang, 2014), matched condition data were combined. Given limited trials per condition (12) and low repetition (each exemplar appeared only twice), median RTs were used to represent participant responses (Tian & Huber, 2010; Yuan et al., 2016).

Errors and RTs below 300 ms or above 3000 ms were removed (8% in 3a, 10% in 3b). Average accuracy exceeded 95% in all conditions. Two-way repeated measures ANOVAs on Experiment 3a data revealed no significant effects (accuracy: $F(1, 11) < 0.45$, $p > 0.515$; RT: $F(1, 11) < 1.14$, $p > 0.078$).

Experiment 3b analyses revealed no significant accuracy effects ($F(1, 11) < 1.21$, $p > 0.295$). For RT, the satiation level main effect was significant, $F(1, 11) = 5.15$, $p = 0.044$, $\eta^2_p = 0.319$, with slower responses in high satiation (1176 ms) than low satiation (1118 ms). The delay main effect was significant, $F(1, 11) = 14.63$, $p = 0.003$, $\eta^2_p = 0.571$, with slower responses at first judgment (1238 ms) than second (1056 ms). The interaction was not significant, $F(1, 11) = 0.04$, $p = 0.839$.

Discussion

Because few objects maintain constant color, insufficient consensus-rated vocabulary materials were available for extensive semantic judgment tasks. Therefore, Experiment 3 included semantic judgments at only two time points. Considering potential attentional dispersion during long waiting periods, we noted that in Experiments 1 and 2, completing half the visual search trials required approximately: warning (800 ms) + fixation (1000 ms) + $6 \times$ (stimulus duration (200 ms) + response window (1800 ms) - final window (1800 ms)) = 12 seconds. We therefore inserted tasks at 2 s and 11 s post-manipulation, with the first judgment (1+ s) plus interval (11 s) approximating half the visual search duration.

Experiment 3a showed no semantic function change after fatigue. Experiment 3b showed semantic satiation effects persisted through half the visual search task. To test whether Experiment 2 data differed between halves, we conducted a four-way ANOVA splitting RT data into first and second halves. The four-way interaction was not significant, $F(2, 19) = 0.204$, $p = 0.817$, $\eta^2_p = 0.021$, indicating consistent effects across halves that could be combined. Thus, Experiment 2' s visual search task occurred under sustained semantic satiation.

General Discussion

This study experimentally manipulated perception and language independently to observe immediate effects on CCP when either function was altered in isolation. Under color vision fatigue, language processing remained unchanged while color vision processing changed, altering CCP and demonstrating that perceptual processing contributes to CCP mechanisms. Under semantic satiation, perceptual processing remained unchanged while semantic processing changed, also altering CCP and demonstrating that semantic processing contributes to CCP mechanisms. Compared to studies using participant characteristics, this approach provides stronger operational control with fewer confounding factors.

Our findings confirm that CCP is influenced by both perceptual and linguistic factors, consistent with the VLC model. The model explicitly proposes encoding, comparison, and decision stages: perceptual information leads to “different” judgments for both BC and WC discrimination (no difference), while semantic information leads to “same” judgments for WC and “different” for BC discrimination. The mismatch between semantic and perceptual information for WC trials creates cognitive conflict, producing CCP. ERP evidence supports this model: Liu et al. (2010) found right visual field CCP effects related to inhibition of linguistic information during WC discrimination. Holmes, Franklin, Clifford, and Davies (2009) found that early processing (P1, N1) showed shorter latencies for BC than WC stimuli, while later processing (P2, P3) showed stronger activation for BC stimuli, demonstrating dual perceptual and linguistic influences.

However, the VLC model does not specify the detailed processing mechanisms within perceptual and linguistic encoding, limiting its ability to explain some phenomena. For instance, Hu et al. (2014) suggested that biasing processing to-

ward linguistic encoding speeds “different” judgments for BC discrimination, yet perceptual encoding alone can also produce “different” judgments, and semantic information is not necessarily more effective when no conflict exists. Additionally, Experiment 1 found stronger CCP under fatigue (impaired perceptual processing), suggesting that color information suppresses CCP. Yet studies show CCP in pre-linguistic infants and primates (Franklin et al., 2005; Franklin et al., 2008a; Skelton et al., 2017; Tajima et al., 2016), indicating that perceptual suppression of CCP is not innate. Under certain conditions, perception may promote CCP. Adult color perception is influenced by linguistic experience, potentially transforming early perceptual CCP into linguistic CCP (Franklin et al., 2008a). However, according to the VLC model, without language participation, no perceptual-linguistic conflict would exist and CCP would not occur, suggesting the model requires refinement.

In fact, CCP may be influenced by three factors: independent perceptual effects, independent linguistic effects, and perceptual-linguistic interactions. The VLC model primarily addresses the interaction while leaving specific mechanisms within each system underexplored. Experiment 2’s finding that satiation affected identical-WC discrimination demonstrates that changes within the linguistic processing module itself can alter CCP. Future research should employ methods to “open the black box” of perceptual and linguistic encoding in CCP, examining how internal mechanisms within each system affect the phenomenon.

Recent research offers new perspectives on specific processing mechanisms. Abbott, Griffiths, and Regier (2016) and Tajima et al. (2016) used Bayesian models to study color category emergence and discrimination from learning and evolutionary perspectives. Tajima et al. (2016) proposed that hue-selective neurons correspond precisely to specific wavelengths in perception, with only narrow wavelength ranges producing excitation, while category-selective neurons respond to broad wavelength ranges. Human CCP results from combined activation of both neuron types. Bayesian models describe “micro-level” phenomena within information processing modules, while the VLC model describes “macro-level” phenomena between modules. Future research should integrate internal micro-mechanisms with external macro-mechanisms, with further neurophysiological studies providing stronger evidence for CCP models and our conclusions.

In summary, CCP requires both perceptual and semantic information, and altering either processing ability affects the effect. In adults, perceptual information suppresses CCP while semantic information enhances it, supporting the VLC model.

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