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ARTICLE

Effects of Color on the Buildup and Resolution of Proactive Interference in Working Memory

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ABSTRACT

The "color superiority effect" was confirmed by the research of color on forgetting, which showed that proactive interference (PI) has less impact on colored items than gray ones. Color could directly affect the buildup of PI, leading to reduced levels of interference, or controlled processes that resolve PI. However, the effects of red and green on memory were inconsistent. Using Recent-Probes task, the current study explored how the red and green color influenced to the buildup phase (i.e., 200ms after the onset of probe) and resolution phase (i.e. 800ms after the onset of probe) of PI. Results revealed that the reaction times of green words were significantly shorter than the red words under 200ms. There were no significant differences between the red and green words under 500ms and 800ms. It indicated that green might shortened the reaction times for the PI buildup, while red prolonged it. However, on the resolution phase of PI, green words were less effective than red words. These findings offered some new information for the underlying mechanisms that modulate the interactions between color and memory.

1. Introduction

The "color superiority effect" in memory refer to a memory effect that individuals generally recognized colored items better than black-and-white ones [1-3]. However, researchers found the various color had different influence on the individual memory. For example, "green supremacy effect" was found, in which participants showed a better memory performance for green-colored items, compared with red-colored items [4]. But the other study found that memory for red -colored items was particularly higher than green [5]. Therefore, further research about the mechanisms of red and green color on memory is needed.

Proactive Interference (PI) is the interference from prior memories, which thought to contribute to the individual forgetting and also positively associated with Working Memory (WM) capacity [6]. Researchers found that it had better performance in the presence of PI when the stimuli were given various colored compared to gray stimuli. The result confirmed "color superiority effect" based on the perspective of PI, and indicated that color

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increased the discriminability between content-context bindings in WM [7].

In recent years, researchers proposed that the PI should be composed of different stages, i.e. the buildup of PI, reflecting the early/automatic familiarity-based processes, and the resolution of PI, reflecting the later/controlled processes that access contextual information [8]. Mızrak and Öztekin [9] found that negative emotional stimuli led to a slower buildup of PI, but in the resolution of PI it was less effective than neutral stimuli. The other study showed that positive emotional stimuli might contribute to the resolution of PI [10].

The colors red and green seem also to have relevance in emotional contexts [11]. Typically, red is used as a signal for negative, especially threatening information (e.g., alarms, warning signals), whereas green signals security and safety [12].

Given the ubiquity of such color usage in everyday life, red and green might have acquired the function of implicit cues alerting the perceiver to imminent danger or potential benefits. Studies showed that red was strongly associated with dominance and arousal, but green was slightly associated with arousal. And green was slightly more pleasurable than red [13,14]. Therefore, whether red and green, which are associated with different emotions, also have different effects on the buildup and resolution of PI, which is a new perspective to explore the effect of different colors on memory.

On the basis of the investigations, the present study used 200, 500, or 800 ms as the duration of response deadline to Recent-probes task consisting of red, green and blue (as a control color) words to explore the effects of red and green on the buildup and resolution of PI. We hypothesized that red and green could impact the buildup and resolution of PI differently. Red and green would have higher accuracy and shorter reaction times than blue stimuli when PI buildup. But the resolution of PI for red stimuli was less effective than green in accuracy and reaction times.

2. Methods

2.1 Participants

32 healthy adults (16 males and 16 females) were recruited for this study and received monetary compensation. The average age was 22 years (range 20 - 26 years). All participants were right-handed and had normal or corrected-to-normal vision. Informed consent from all participants was obtained in accordance with the Ethical Committee of Capital Normal University.

2.2 Material

906 Chinese words were selected from the Modern Chinese frequency dictionary (Liu, 1990), with means of 106.99 on frequency, ranging from 5 to 2042. Before the experiment, twenty students who did not participate in the experiment were randomly invited to rate the words' valence on a scale ranging from 1 (lowest pleasure) to 9 (highest pleasure), the arousal on a scale ranging from 1 (lowest arousal) to 9 (highest arousal), the familiarity from 1 (very unfamiliar) to 9 (very familiar). Rating by college students, the 906 words were chosen with neutral valence (M = 5.08, SD = 0.43), medium arousal (M = 3.03, SD = 0.5), medium familiarity (M = 6.84, SD = 0.91).

There were no significant differences between the words used as targets and lures on frequency, $t\,(452) = 0.02$, $p > 0.05$; valence, $t\,(452) = .97$, $p > 0.05$; arousal, $t\,(452) = 0.19$, $p > .05$, and familiarity, $t\,(452) = 0.14$, $p > 0.05$. All the words used in the experiment were 14 points in bold with Microsoft black made in Photoshop. The properties of the three colors were chosen according to the RGB model (red: 255, green: 0, blue: 0; green: 255, red: 0 and blue: 0; blue: 255, green: 0, red: 0).

2.3 Design

The experiment adapted the Recent-Probes Task (RP Task), a widely used paradigm to induce PI by presenting lures from previous study list (see Figure 1). Participants are given a series of trials in which they are presented a target-set of items to commit to memory, then they are given a single probe item and must decide whether this probe matches one of the items in that trial's target-set. Some probes will match one of the target-set items, thereby eliciting a positive response while some will not match and will elicit a negative response. On some of the trials, a probe that had not been a member of the current trial's target-set was drawn from the previous trial's target-set (called "recent negative probes"). On other trials, the negative probes had not appeared recently as members of other target-sets ("non-recent negative probes"). This manipulation was also applied to positive probes to yield recent and non-recent positive probes [15].

For trials when the target-set included four items, Monsell [16] showed that recent-negative probes yielded responses that were approximately 75 ms longer and 7% less accurate than non-recent negative probes. That is, there was PI from the previous trial's target-set on the current trial's negative response. Therefore, PI was calculated as the difference between recent negative and non-recent negative trials, and non-recent trials could be used to assess participants' global Working Memory (WM) performance

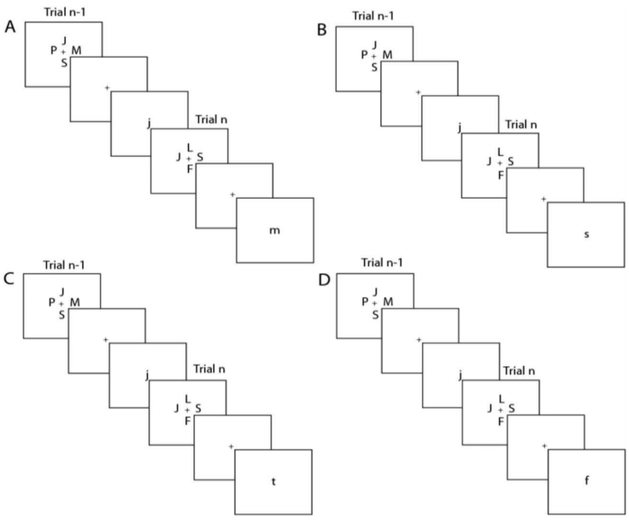

Figure 1. A schematic of the Recent-Probes Task. The four panels show the four central conditions. Panel A represents the recent-negatives (RN); Panel B represents recent-positives (RP). Panel C represents non-recent negatives (NN); and Panel D represents non-recent positives (NP)

In addition, in RP Task, the buildup and resolution of PI can be investigated by controlling of the presentation time of the recognition probe [9]. At early, middle or late period after the onset of the recognition probe, a tone sounded to cue participants to respond as soon as possible. When the probes were presented for a shorter time (200ms), subjects tended to make fast assessment based on the familiarity information, in which the buildup of PI could be observed. When the probes were presented for a longer time (800 ms), individuals had enough time to retrieve contextual information, in which the resolution of PI could be observed. When the probe was presented for a moderate time (500 ms), the familiarity-based processes was being replaced by controlled processes, in which the initial phase of PI resolution could be observed.

2.4 Procedure

Figure 2 showed below illustrated the sequence of events in a single trial. Each trial began with 500ms of fixation, followed by a target set with three words all in red, blue or green for 1,000 ms in a 2 ×1 array and retained in memory during a retention interval of 1000ms. This interval was followed by a single black word as a recognition probe. At 200 ms, 500 ms or 800 ms after the onset of the probe, a 50 ms tone sound cued participants to respond whether or not the probe was presented in the target set by pressing mouse button. Participants were indicated to provide “yes” (left mouse button) or “no” (right mouse button) as quickly as possible after the onset of the tone. After providing a response, they were given feedback on their reaction times. They were informed that responses longer than 300 ms were too slow and responses less than 100 ms were anticipations, and both should be avoided. Participants were trained to respond within 300 ms after the tone. Stimulus were presented by Eprime software.

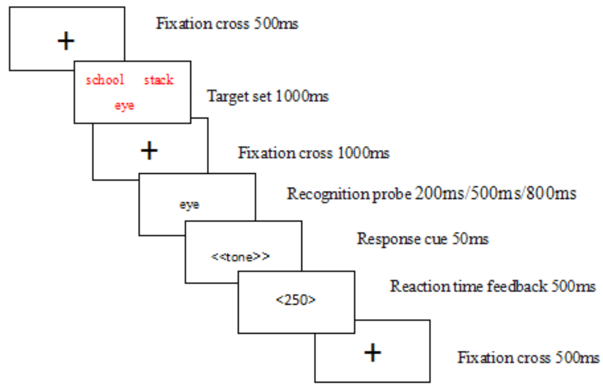

Figure 2. Example of one experimental trial

The red, blue and green conditions were tested in three different sessions. Each session consisted of 4 blocks of 48 trials, including 24 positive trials, 12 recent negative (RN) trials and 12 non-recent negative (NN) trials. Before beginning the experiment, subjects were given written and oral instructions and completed 10-min practice session under supervision by an experimenter using stimuli from different pools of words than those used during the experimental trials.

2.5 Statistical Analyses

Data collected included accuracy (ACC) and response times (RTs). RTs were calculated for correct trials only. Responses faster than100 ms, and longer than 600 ms were excluded from analyses. Repeated measures analyses of variance (ANOVAs) were performed separately on accuracy (ACC) and RT data. To explore the effect of color on PI during short-term item recognition, only the negative probes were analyzed. Secondly, the analyses of non-recent probes provided information about the impact of color on WM performance. Two parts of the analyses could not only help us to explore the effects of color on the buildup and resolution of PI, but also whether the color had the same impact on PI and WM performance.

3. Results

3.1 The Impact of Color on the Buildup and Resolution of Proactive Interference

Analyses of responses to RN and NN provided us the result of color on PI. Responses based on familiarity which

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were dominant in 200 ms, reflected the buildup of PI, and those based on recovery of contextual information that were dominant in 800 ms, reflected successful resolution of PI.

3.1.1 Accuracy

An overview on descriptive measures about accuracy (ACC) of negative probes was provided in Table 1. Using a 3 (color: red, blue, and green) × 3 (response deadline: 200 ms, 500 ms, and 800 ms) × 2 (recency: recent negatives vs. non-recent negatives) analysis of variance (ANOVA) on accuracy scores, main effects of response deadline, [$F(2, 62) = 50.45$, $p < 0.01$, $\eta^2_p = 0.619$], and recency [$F(1, 31) = 24.68$, $p < 0.01$, $\eta^2_p = 0.443$] were found, as well as significant response deadline × recency interaction [$F(2, 62) = 25.68$, $p < 0.01$, $\eta^2_p = 0.453$]. No color × response deadline [$F(4,124) = 0.573$, $p = 0.65$, $\eta^2_p = 0.018$] nor color × recency [$F(2,62) = 0.898$, $p = 0.399$, $\eta^2_p = 0.028$] interaction was found, which meant that the ACC of negative probes was comparable across the three colors.

Follow-up pairwise comparisons revealed that for all experimental conditions, ACC in the RN trials was siginificantly lower than NN trials ($p < 0.001$), and the ACC of RN probes was lowest under 200 ms (M=0.79) compared with 500ms (M=0.90) and 800ms (M=0.93) ($p < 0.001$). Cause that PI could be calculated as the difference between compared trials. The result indicated that the ACC of participants were subject to PI under all respond deadlines, but the influence of PI under 200ms was more significant than 500ms and 800ms (see Figure 3).

Table 1. Means and standard deviations (in parentheses) of accuracy of negative probes in the RP Task

Probe Condition	Red words			Blue words			Green words		
	200ms	500ms	800ms	200ms	500ms	800ms	200ms	500ms	800ms
RN	0.78 (0.16)	0.91 (0.13)	0.94 (0.1)	0.79 (0.17)	0.89 (0.16)	0.92 (0.14)	0.80 (0.16)	0.91 (0.11)	0.94 (0.09)
NN	0.93 (0.1)	0.98 (0.03)	0.98 (0.04)	0.94 (0.06)	0.98 (0.05)	0.99 (0.04)	0.93 (0.09)	0.99 (0.03)	0.98 (0.03)

Note:

RN means recent negative probes; NN means non-recent negative probes.

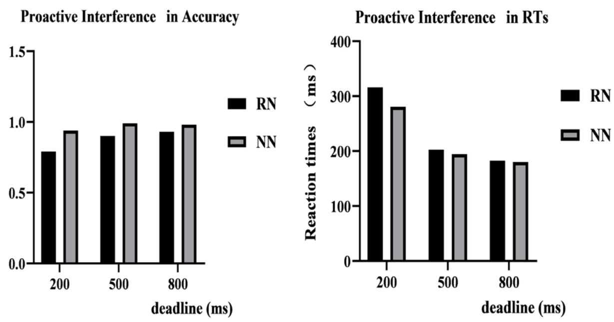

Figure 3. Proactive Interference in accuracy under response deadlines of 200ms, 500ms, and 800ms. RN means recent negative probes. NN means non-recent negative probes

3.1.2 Reaction Times

The analyses of reaction times (RTs) restricted to trials for which a correct response was provided. An overview on descriptive measures about RTs of negative probes was provided in Table 2. A repeated-measurements ANOVA with color (red, blue, and green) × response deadline (200ms, 500ms, and 800ms) × recency (recent negatives vs. non-recent negatives) resulted in a significant interaction between color and deadline, $F(4, 124) = 3.06$, $p < 0.05$, $\eta^2_p = 0.09$. Following a simple effect analysis, we detected a significant color difference when the response deadline was 200ms ($p < 0 .05$) and a marginally significant color difference under 500ms ($p = 0.08$), but we did not find a color difference under 800ms ($p = 0.94$). Under 200ms, the RTs of green words (M=291.67) were significantly shorter than red words (M=304.78). While it had not shown any significant difference across all colors under 500ms and 800ms. The result indicated that compared with red, green color might shortened the RTs during the PI buildup, while the resolution of PI for green words was less effective than red words (see Figure 4). Furthermore, the RTs under 200ms were significantly longer than 500ms and 800ms under three colors ($p < 0 .05$), which indicated that the effect of PI under 200ms is bigger than 500ms and 800ms under all three colors.

In addition, the results showed a main effect of recency, $F(1, 31) = 68.77$, $p < 0.01$, $\eta^2_p = 0.689$, a main effect of response deadline, $F(2, 62) = 290.12$, $p < 0.001$, $\eta^2_p = 0.903$ and a significant interaction between response deadline and recency, $F(2, 62) = 35.17$, $p < 0.01$, $\eta^2_p = 0.532$. Further simple analysis showed that recent probes were answered slower than non-recent probes under 200ms (NN: M=280.99, RN: M=316.13, $p < 0.001$) and 500ms (NN: M=202.60, RN: M=194.66, $p < 0.01$), but was not under 800ms ($p > 0.05$), which indicated that the RTs of

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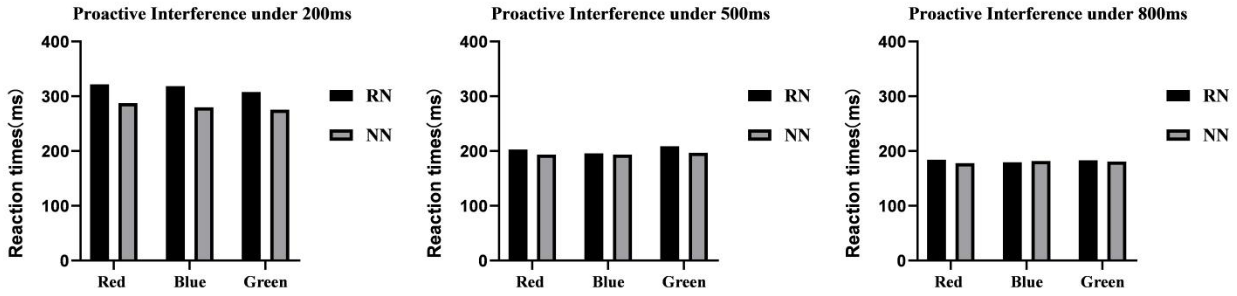

Figure 4. Reaction times in negative probes under 200ms, 500ms and 800ms. RN means recent negative probes; NN means non-recent negative probes

participants were subject to PI under 200ms and 500ms, but the influence of PI was not significant under 800ms. Besides, the RTs of RN probes under 200ms (M=316.13) were significantly longer than 500ms (M=202.60) and 800ms (M=182.39) ($p < 0.001$), which indicated that the influence of PI under 200ms is bigger than 500ms and 800ms (see Figure 5).

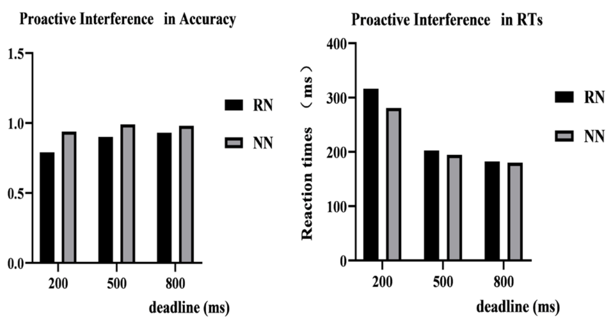

Figure 5. Proactive Interference in reaction times under response deadlines of 200ms, 500ms, and 800ms. RN means recent negative probes. NN means non-recent negative probes

3.2 The Impact of Color on Working Memory

Cause that non-recent positive (NP) and non-recent negative probes (NN) were free from the influence of PI in RP Task, analyses of responses to NN and NP provided us the result of color on WM performance.

3.2.1 Accuracy

An overview on descriptive measures about ACC of non-recent probes was provided in Table 3. A 3 (color: red, blue, and green) × 3 (response deadline: 200ms, 500ms, and 800ms) × 2 (probe type: positive vs. negative) analysis of variance (ANOVA) on accuracy scores revealed significant effect of color, [$F(2, 62) = 6.63$, $p < 0.05$, $\eta^2_p = 0.176$], a main effect of probe type, [$F(1, 31) = 25.92$, $p < 0.01$, $\eta^2_p = 0.455$], a main effect of response deadline [$F(2, 62) = 51.80$, $p < 0.01$, $\eta^2_p = 0.626$], and a significant interaction between color and probe type, [$F(2, 62) = 3.32$, $p < 0.05$, $\eta^2_p = 0.097$].

Follow-up pairwise comparisons revealed that ACC of blue words (M=0.92) were significantly higher than green words (M=0.89) under NP probes ($p < 0 .05$), which indicated that compared with green words, the ACC of WM performance was higher with blue words. In addition, NN were answered more correctly than NP under all three colors ($p < 0.001$). The ACC under 200ms (M=0.90) was reliably higher than 500ms (M=0.96) and 800ms (M=0.95), which showed that the AAC of WM performance under 200ms was higher than 500ms and 800ms.

Table 2. Means and standard deviations (in parentheses) of reaction times of negative probes in the RP Task

Probe condition	Red words			Blue words			Green words		
	200ms	500ms	800ms	200ms	500ms	800ms	200ms	500ms	800ms
RN	321.99 (61.72)	202.93 (33.86)	184.27 (24.85)	318.57 (57.23)	195.99 (34.31)	179.58 (40.25)	307.83 (51.51)	208.88 (42.85)	183.32 (37.78)
NN	287.57 (54.34)	193.64 (30.80)	177.95 (29.95)	279.88 (54.06)	193.63 (31.44)	181.71 (29.60)	275.5 (50.23)	196.71 (37.07)	180.92 (30.67)

Note:
RN means recent negative probes; NN means non-recent negative probes. Reaction times were displayed in milliseconds.

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Table 3. Means and standard deviations (in parentheses) of accuracy of non-recent probes in the RP task

Probe condition	Red words			Blue words			Green words		
	200ms	500ms	800ms	200ms	500ms	800ms	200ms	500ms	800ms
NN	0.93 (0.10)	0.98 (0.03)	0.98 (0.04)	0.94 (0.06)	0.98 (0.05)	0.99 (0.04)	0.93 (0.09)	0.99 (0.03)	0.98 (0.03)
NP	0.86 (0.14)	0.94 (0.08)	0.91 (0.1)	0.89 (0.1)	0.96 (0.08)	0.92 (0.12)	0.82 (0.13)	0.93 (0.08)	0.92 (0.12)

Note:
NN means non-recent negative probes; NP means non-recent positive probes.

3.2.2 Reaction Times

An overview on descriptive measures about RTs of non-recent probes was provided in Table 4. A repeated-measurements ANOVA with color (red, blue, and green)×response deadline (200ms, 500ms, and 800ms) × probe type (positives vs. negatives) revealed main effects of response deadline, [$F(2, 62) = 231.25$, $p < 0.01$, $\eta^2_p = 0.882$]. Follow-up pairwise comparisons revealed that RTs of non-recent probes under 200ms (M=284.19) were significantly longer than 500ms (M=195.41) and 800ms (M=181.72) ($p < 0.001$), which indicated that the RTs of WM performance under 200ms was longer than 500ms and 800ms.

4. Discussion

The present study explored the effects of color (red and green) on the buildup and resolution of PI. Results revealed that the reaction times of green words was significantly shorter than the red words under 200ms. There was no significant differences between the red and green words under 500ms and 800ms. In addition, the accuracy of blue words was significantly higher than green under NP probes. Detailed results were summarized and discussed in the following sections.

4.1 Effects of Color on the Buildup and Resolution of Proactive Interference

The comparison of responses to RN and NN provided us the result of color on PI, which showed that the RTs of green words was significantly shorter than the red words under 200ms, indicating that green might shortened but red prolonged the RTs when the PI buildup, which was a supplement to the "green supremacy effect " [4]. Studies revealed that color could convey emotion information [11]. Green was slightly associated with arousal and increased wellbeing and enjoyment, while red was relevant to threatening situations and high-arousal state [13,18]. Using RP Task, Levens and Phelps [19] found that the RTs of high-arousing negative trial were longer than low-arousing neutral trial, which were likely due to an avoidance effect associated with highly arousing negative stimuli that slowed response time. Therefore, compared with green, red with high-arousal might induce avoidance effect which need longer reaction times to inhibition the familiarity information.

In addition, the result showed that the difference between RN and NN under 200ms is bigger than 500ms and 800ms both in ACC and RTs, which indicated that the effect of PI is bigger under 200ms than 500ms and 800ms. The result confirmed previous study about the buildup and resolution of PI [8,9]. That is, when the probes were

Table 4. Means and standard deviations (in parentheses) of reaction times of non-recent probes in the RP task

Probe condition	Red words			Blue words			Green words		
	200ms	500ms	800ms	200ms	500ms	800ms	200ms	500ms	800ms
NN	287.57 (54.34)	193.64 (30.80)	177.95 (29.95)	279.88 (54.06)	193.63 (31.44)	181.71 (29.60)	275.5 (50.23)	196.71 (37.07)	180.92 (30.67)
NP	288.68 (45.92)	194.94 (32.18)	179.30 (31.13)	282.28 (43.84)	197.70 (29.03)	183.66 (36.97)	291.23 (50.25)	195.83 (27.65)	186.79 (30.19)

Note:
NN means non-recent negative probes; NP means non-recent positive probes. Reaction times were displayed in milliseconds.

presented for 200ms, the buildup of PI could be observed, subjects were more likely to make mistakes and need longer reaction times to make a choice. When the probes were presented for 800ms, the resolution of PI could be observed, individuals were less likely to make mistakes and have shorter reaction times.

4.2 General Effects of Color on Working Memory

Analyses of the non-recent positive and non-recent negative probes were aim at studying the effect of color on WM performance. The result showed that the ACC of green words was lower than blue words under NP probes, which should be related to the color preference of adults. Some studies found that the overall color preference order of the adults was blue, red, green, yellow and so on.

Furthermore, the result showed that the impact of color on the PI and WM performance is different in RP Task, which was inconsonant with hypothesis. It implied that PI might constituted a relatively independent phenomenon with WM [20]. Hartshorne [21] found that PI only changed the visual WM capacity estimate by about 15%. Although the quality of WM was related to the buildup and resolution of PI, the processing mechanisms might be different to some degree. Moreover, the result showed that negative trials were answered more correctly than positive, which was consistent with the previous researches [15]. Namely, there was a competition between familiarity and contextual information for NP probes, which might result in the probability of false response. By contrast, NN probes will have low familiarity and no contextual tags linking them to the current target-set, which tended to yield right response because of no competition between two types of information.

In summary, the present study offered a unique contribution to the literature by showing the effects of color on the buildup and resolution of PI. Green aided memory by slowing down the PI buildup, while red impaired memory by speeding up the PI buildup, which provided an explanation for the facilitating effect of green on memory previously observed. In contrast to the effect of color on the buildup of PI, the present study indicated that color had no effect on PI resolution, which could give insight into the underlying mechanisms that modulate the interactions between color and memory. In addition, the results of the current study could be of considerable importance for applied fields as well, which suggested that it was necessary to take different effects of specific colors on information memory into account.

Finally, a few possible issues and further investigations were needed to be noted. Firstly, researchers found that words outstanding by color from the context had the better memory performance [11]. Our result showed that the accuracy was not remarkably different between red and green words under three deadlines. The reason might be that color was not perceptually outstanding in current experiment, which lead to a decreased discriminability between content-context bindings. Therefore, using color as a perceptually more salient signal to explore the effect of color on PI buildup and resolution would be an important avenue for future research. Besides, considering that accuracy of words in blue is highest in WM, in which blue did not play the role of control condition. Cultural cognition has reported that differences in color processing between individuals from East Asian and Western cultures [22], thus, changing control color for black or gray might be next direction of the research about color and PI.

Declarations

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Conflict of interest: The authors certify that the submission is original work and is not under review at any other publication and that there are no potential conflict of interest.

Ethics approval: All procedures performed in studies involving human participants were in accordance with the Ethical Committee of Capital Normal University.

Informed consent: Informed consent was obtained from all individual participants in the study.

Authors' contribution statements: All authors contributed to the study conception and design. Rong Liu and Weichun Du designed the study. Chenyuan Zhao, Weichun Du, Fengxia Su and Sixu Qiao collected and analyzed the experimental data. Rong Liu and Weichun Du wrote the article draft. Lixuan Feng analyzed the experimental data preliminary and proofreaded the article. Rong Liu revised and finalize the manuscript.

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