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Attention-operated working memory representations determine visual selective attention

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Abstract:

It has been demonstrated that visual attention is guided by information actively maintained in working memory (WM). However, it remains unknown whether other operations (e.g. inhibition) on WM contents influence selective attention. This issue was investigated in a visual search task where WM contents with either operation (maintenance or inhibition) appeared as distractors in the search display. Behavioral results showed that search performance was slowed down for presenting the maintained contents, but speeded up for the inhibited contents. These results suggested an operation-directed selection of WM contents that visual attention was distinctively influenced by contents with different operation. These observations were further confirmed by the indexes of event-related potentials (ERPs). The inhibited WM contents were suppressed at sensory gating stage (i.e., suppressed P1 amplitude), while the maintained WM contents guided visual attention (i.e., enhanced N2pc amplitude). It seems that results from ERPs and behavior are integrated. The maintained contents guided visual attention that hindered performance of searching a target, while the inhibited contents screened attention that facilitated target searching in the other space. Besides, P3 component indexing updating of WM, which revealed comparable latency both for the maintained and the inhibited WM contents, but with longer latency than the neutral contents. These results suggested that the WM contents with distinct operations were expelled from the focus of executive attention after the onset of the search task, which might be necessary for the WM contents influencing selective attention. The current study reveals that operations of WM contents distinctively affect early selective attention to the matching contents, which sheds some light on the interaction between WM and visual attention.

Key words: selective attention; working memory (WM); event-related potentials (ERPs); attentional operation; inhibition

1 Introduction

Working memory (WM) and attention are closely related. As we know, information maintained in WM has been demonstrated to influence selective attention . However, other studies have revealed no evidence of the influence of WM contents on attention . Thus, further investigation is required to fully understand the controversy over the influence of WM contents on attention and its underlying mechanism.

The finding that the visual attention of a search task is biased to the content maintained in the concurrent WM task, suggests a guidance effect driven by memory content . Additionally, the guidance effect is automatic (Soto, Heinke, Humphreys, & Blanco, 2005) and robust even in presence of a salient search target (Soto, Humphreys, & Heinke, 2006). However, other studies have showed no guidance effect of the maintained WM contents when the task of selective attention requires active representation . As we know, the number of items processed with the executive attention is limited (Menneer et al., 2007; Oberauer, 2002), thus in the dual task the WM contents and the search target would compete for attentional focus. In these studies, the target was actively represented , which occupied attentional focus. In the meanwhile, the WM contents that were stored but not under executive attention resulted in diminished or disappeared guidance effect. Above all, there were two different (stored and executive) states of WM that the contents under executive state influence visual attention while do not affect attention when merely stored . It seems that the ongoing processing of WM contents with executive attention may be critical in influencing visual attention.

As we know, the executive function of the WM involves two distinct operations, maintenance and inhibition . As previous studies focused on the influence of the maintained WM contents on attention, little is known about the selective attention influenced by inhibitory operation of the contents. The inhibitory operation excludes irrelevant information and suppresses distractors, which has been emphasized in numerous studies . Moreover, the top-down suppression of irrelevant information is essential and always online to obtain optimal performance . As an important executive function, the inhibitory operation is an indispensable part to reveal the mechanism of the interaction between selective attention and WM contents. Notably, the investigation whether the inhibited WM contents have an influence on attention can directly examine the previous view, which suggests WM contents under executive attention do affect selective attention (. Additionally, comparison between the selective attention influenced by the inhibited contents and that by the maintained contents will shed some lights on the relationship between selective attention and WM contents with distinct operations.

As we noted above, it is probably the executive attention operated on the WM contents that influence selective attention to the matching information in a task of selective attention. However, it still unclear whether the contents under executive attention or contents with specific operation affect selective attention. Herein, two alternative predictions are proposed to resolve this question, the attention-directed guidance and the operation-directed selection. As we mentioned, operations (maintenance and inhibition) of the WM contents involves executive attention, thus that the contents are processed within the attentional focus and easily gain control of visual attention . Based on this view, the attention-directed guidance suggests that the matching contents under executive attention will be more accessible and attract visual attention in the other task. Therefore, the attention-directed guidance predicts that both the maintained and the inhibited WM contents capture visual attention, demonstrating analogous pattern of selective attention. However, the operation-directed selection acknowledges the accessibility of contents under executive attention, and further posits that the specific operation (maintenance or inhibition) on executive attention determines the selective attention of perceptually matching contents. In other words, the maintained content is attended and the inhibited content is suppressed when they appeared in the visual field. This view predicts that the contents with maintained operation and the contents with inhibitory operation have distinct pattern of selective attention.

In the current experiment, a dual-task incorporating WM task and visual search task was utilized, modified from Olivers et al. (2006). In the WM task, two colors were memorized first, and then a cue pointed the color to be maintained and the other to be inhibited. The stimuli were presented on the bilateral visual fields in the search array, which enabled an examination on lateralized processing indicative of the selective attention (Heinze et al., 1990; Luck and Hillyard, 1994a). Additionally, the cued or uncued WM contents might appear on the opposite field to the search targets. A baseline (neutral condition) was established when there was no memory item in the search array. Applying a moderate duration between the WM task and the search task suggest, the cued and the uncued WM contents were supposed to be differently operated (maintained and inhibited, respectively) under executive attention. If the attention-directed guidance determines the influence of WM contents on attention, both the maintained (cued) and the inhibited (uncued) WM contents will guide attention and impair search performance. Alternatively, the operation-directed selection forecasts an adverse effect for the presence of the maintained WM contents and a beneficial effect for the inhibited WM contents in the search task.

In addition to the behavioral measurement, electrophysiological method was also employed to further reveal the neural mechanism of selective attention influenced by WM operations. Electroencephalogram (EEG) data were recorded while healthy human participants were performing the dual-task. Early ERP (event-related potential) components (e.g., P1 and N1) were adopted to index the selective attention influenced at sensory gating stage . The attentional guidance effect could be reflected by the N2pc component , which is sensitive to spatially selective attention . Additionally, P3 was also examined as the late attentional components .

2 Method

2.1 Participants

Twenty-four (11 females, aged between 18 and 25 years) right-handed college students at Southwest University were recruited in return for a monetary reward. All participants reported normal or corrected-to-normal visual acuity and normal color vision. Informed consent was obtained from them all. This study was approved by the Review Board of Southwest University (Chongqing, China) for Human Participant Research.

2.2 Apparatus, stimuli and procedure

E-Prime software (version 1.1, Psychology Software Tools Inc. Pittsburg, USA) was used to control the stimuli and collect responses. The stimuli were displayed on a 17-inch monitor with a resolution of 1,024 × 768 pixels and a refresh rate of 85 Hz. The distance between the monitor and participants was approximately 70 cm.

Stimuli were presented on a gray background (RGB values: 128, 128, 128). The color patch was 1.6° × 1.6° visual angle. Ten colors were chosen from the Munsell's color system consisted of five principal hues (red, yellow, green, blue and purple). The hue, brightness and chroma of these colors were listed in Table 1. The specific hue and value were kept nearly constant. The chroma of each color varied between 8 and 12. Note that these colors used in the present experiment were only approximations of Munsell's original colors due to screen limitations. The vertical line was 0.8° × 0.1° visual angle, and the target was tilted 15°. In the search array, four lines were presented and each was put on the middle of the color patch as an object.

The trial sequence of this experiment was shown in Figure 1. Each trial began with a black cross presented for 500 ms. After that, a memory array with two colors was presented for 1500 ms, and participants were required to remember both colors. The color patches were presented on the middle line that deviated 1.5° up and down from the center fixation. Following that, a mask array of 500 ms contained two Mondrian patches, which presented on the same locations as color patches in the memory array. At the last 200 ms of the mask array, an arrow was added on the fixation, introducing distinct attentional operations (i.e., maintenance and inhibition) on the memory colors. The arrow pointed to the color to be tested and was maintained, but the uncued color was irrelevant and supposed to be inhibited. The inter-stimulus interval between the mask array and the search array was randomized between 1000 ms and 1200 ms. The search array contained four objects on separate quadrants in an imaginary clock face with a radius of 6.5°. The colors of objects were different in the left and in the right visual field, but identical in each visual field. Participants responded to the position of the target (i.e., in the left or right visual field). After an interval of 500 ms, the test array with two different color patches was displayed horizontally, in which a response about the presence of the cued color was required. Both the search array and the test array was presented until a response or 3000 ms. The inter-trial interval was 500 ms.

2.3 Assignment of stimuli

Locations of stimuli were controlled with balance. In the mask array, an upward arrow appeared on half of the trials and a downward arrow appeared on the remaining half trials. In the search array, the targets presented on four quadrants evenly. The cued color and the uncued color were located in the left and the right visual fields for equal probability. The directions of the cue corresponding to the top and bottom locations of the target were counterbalanced and so were the left and right positions of the search target corresponding to that of the cued color in the test.

The colors presented in an array were controlled for some purposes. In the memory array, colors were chosen from two adjacent hues (red, yellow, green, blue and purple) to ensure visual similarity. Thus, the memory colors were supposed to be maintained with visual representation. In the search array, when one of the colors in the memory array appeared, the other color was the most dissimilar one to it. Otherwise, the two colors dissimilar to both memory colors were displayed. Additionally, the luminance contrast and color distance in the search array were approximately equated to avoid difference in physical attributes. In the memory test, two similar colors were chosen to ensure visual representation of the memory colors .

2.4 Design

Since the interaction between operation of visual WM content and visual attention is our main concern, the relationship between the WM contents with distinct operations (the maintained and the inhibited contents) and the search target was manipulated. Specifically, one of the memory colors appeared in the search array on half trials, among which the cued color (cued condition) and the uncued color (uncued condition) was presented in the opposite visual field to the target in equal probability. On the other half of trials, other colors displayed in the search array as neutral condition. Therefore, the Search condition (cued condition, uncued condition and neutral condition) was established. The proportions of the cued condition, the uncued condition and the neutral condition was 1:1:2, to avoid any bias to the memory items.

For the memory test, the cued color and the unced color was presented with equalization and independent of each other. Thus, four combinations constituted by Cued color (presence, absence) and Uncued color (presence, absence) were generated.

Participants in the practice session did 24 trials with feedback of the memory test. After the practice, the experiment with 24 blocks of 24 trials was performed. Trials were assigned with pseudo randomness. Each block took 2-3 minutes, and participants had a self-determined rest.

The whole experiment requires 60-70 minutes. The data from the practice session were excluded from analysis.

2.5 EEG recordings and pre-processing

The electroencephalogram (EEG) data were recorded using a Brain Products system (band pass 0.01-100 Hz, sampling rate: 500 Hz, notch off), connected to a 60 scalp Ag-AgCl electrodes placed according to the international 10-20 system. All inter-electrode impedances were kept below 5 kΩ with the references on FCz and a ground electrode on AFz. The electro-oculograms (EOGs) were simultaneously recorded from four surface electrodes, which were placed over the upper and lower eyelids and next by the outer canthus of the left and right eye to monitor ocular movements and eye blinks. The EEG and electro-oculograms (EOGs) signals were amplified using a DC voltage.

EEG data were pre-processed using EEGLAB 11.0 (Delorme & Makeig, 2004). Continuous EEG recordings band-pass filtered between 1 and 40 Hz. EEG epochs were segmented in 1200 ms time-windows (pre-stimulus 200 ms and post-stimulus 1000 ms) on the search task, and baseline corrected using the pre-stimulus time interval. EEG epochs were then visually inspected and trials with considerable artifacts resulting from gross movements were removed. Trials contaminated by eye-blinks and other movements were corrected using an independent component analysis (ICA) algorithm (Delorme & Makeig, 2004; Delorme, Sejnowski, & Makeig, 2007). In all datasets, the individual eye movements, which showed a large EOG channel contribution and a frontal scalp distribution, were clearly seen in the removed independent components (ICs). After ICA and an additional baseline correction, EEG trials (at least 110 trials in each condition) were re-referenced to the bilateral mastoid electrodes.

2.6 Data analysis

Analyses of behavior data. In the analyses of the search task, data from one participant was excluded due to excessive errors (exceeding three standard deviations). Trials with wrong responses or RTs exceeding 1200 ms, were removed (about 4% of all trials) in the analysis of mean RTs. The one-way repeated-measures analysis of variance (ANOVA) was carried out on the mean RTs and accuracies for the Search condition. All data were analyzed in the memory test with a 2 (Cued color: presence, absence) × 2 (Uncued color: presence, absence) repeated-measures ANOVA.

Analyses of ERP data. The statistics were based on 23 participants with normal errors. Single-participant averaged waveforms in each condition were averaged to get the grand averaged waveform, which were used to obtain the group-level scalp topographies for each condition. The P1, N1, N2pc and P3 components were analyzed in the search task.

The P1 showed a max activation around 100 ms at the lateral parietal-occipital scalp topography. At these electrodes (P1/2, P3/4, PO3/4, and PO7/8), P1 peak amplitudes were detected as the max positive deflection in the time window of 60-130 ms. The 4 (Electrode: P1, P3, PO3, and PO7) × 2 (Hemisphere: left, right) × 3 (Search condition: cued, uncued and neutral) repeated-measures ANOVA was executed on peak amplitudes and latencies.

N1 peak amplitudes were detected at the occipital electrodes (Oz, O1/2, POz and PO3/4), with negative reflection within the time window of 160-200 ms. A 6 (Electrode: Oz, O1/2, POz and PO3/4) × 3 (Search condition: cued, uncued and neutral) repeated-measures ANOVA was carried out on N1 peak amplitudes and latencies.

The N2pc component was sourced at the pooled occipital electrodes (PO7/PO8) and obtained by subtracting the ipsilateral waveforms from the contralateral waveforms of the target. For statistical purposes, the N2pc waveforms were computed with a 100-ms pre-stimulus and 400-ms post-stimulus interval with the pre-stimulus period as a baseline (Figure 4). The mean area amplitudes across 170-250 ms were compared between the contralateral and ipsilateral electrodes with paired-sample t test for each condition. And the N2pc amplitudes in Search condition were obtained by averaging area amplitude across 170-250 ms, which was analyzed with the one-way ANOVA.

The P3 peak amplitude were detected at four posterior midline electrodes (CPz, Pz, POz, and Oz) in a 280-400 ms time range. The two-way (Electrode × Search condition) repeated-measures ANOVA was executed.

The above statistical analysis was carried out with Statistical Product and Service Solutions (version 13.0, SPSS Inc.). Greenhouse-Geisser correction for degrees of freedom was used whenever the assumption of sphericity was violated (p < .05). For multiple comparisons, p values were adjusted using the Bonferroni correction.

3 Results

3.1 Behavioral results

3.1.1 Search task

Figure 2 depicted the mean RTs and error rates in the search task. Mauchly's test of sphericity on RTs was statistically significant ($\chi^2_2 = 12.68$, $p = .002$) on Search condition, so that a validated degrees of freedom was used. There was a significant main effect of Search condition ($F_{2,44} = 935.00$, $p < .001$, $\eta_p{}^2 = 0.61$) on the measures of RTs. Pairwise comparisons indicated that the RTs in the cued condition were 39 ms slower than those in the neutral condition ($t_{22} = 5.37$, $p < .001$, $d = 1.12$), and 49 ms slower than those in the uncued condition ($t_{22} = 7.02$, $p < .001$, $d = 1.46$). Interestingly, performance in the uncued condition was significantly better for 10 ms than that in the neutral condition ($t_{22} = 2.60$, $p = .048$, $d = 0.54$). These results indicated that the appearance of the cued color opposite to the target hindered the selection for the target, while the presence of the uncued colors opposite to the target facilitated visual search. Otherwise, variances were equal in accuracies ($\chi^2_2 = 2.28$, $p = .32$), and no main effect was observed because of high accuracy (over 99%) in all conditions ($F_{2,44} = 1.70$, $p = .19$).

3.1.2 Memory test

The overall mean accuracy in memory task was 84.5%, and the mean reaction time was 831 ms. Analyses on the mean accuracy showed main effects of the Cued color ($F_{1,23} = 29.97$, $p < .001$, $\eta_p{}^2 = 0.57$) with better performance for the presence than the absence of the cued color ($t_{23} = 5.47$, $p < .001$, $d = 1.12$), and the Uncued color ($F_{1,23} = 17.58$, $p < .001$, $\eta_p{}^2 = 0.43$) with worse performance for the presence than the absence of the uncued color ($t_{23} = -4.19$, $p = .001$, $d = -0.86$). Moreover, the interaction between the Cued color and the Uncued color was significant ($F_{1,23} = 7.49$, $p = .012$, $\eta_p{}^2 = 0.25$). The breakdown of this interaction showed a simple effect of the

Uncued color when the cued color was absent in the test ($F_{1,23}$ = 15.82, p =.001, $\eta_p{}^2$ = 0.41). But no simple effect of the Uncued color was observed when the cued color was present ($F_{1,23}$ = 2.75, p =.11). These results demonstrated that uncued color might be mistook as the cued color for its absence.

Correct responses were entered in analysis of the mean RTs. A main effect of Cued color was observed ($F_{1,23}$ = 16.02, p = .001, $\eta_p{}^2$ = 0.41) with faster response for the appearance than absence of the cued color (t_{23}= -4.00, p = .001, d = -0.82). The main effect of the Uncued color was also observed ($F_{1,23}$ = 4.29, p = .05, $\eta_p{}^2$ = 0.16) that RTs were slower with its presence than RTs with its absence (t_{23}= 2.07, p = .05, d = 0.42). An interaction between the Cued color and the Uncued color was also demonstrated ($F_{1,23}$ = 18.92, p < .001, $\eta_p{}^2$ = 0.45). The follow-up tests revealed significant simple contrasts of the Uncued color, reversed for the presence (t_{23}= -2.50, p = .02, d = -0.51) and the absence of the cued color (t_{23}= 4.51, p < .001, d = -0.92). In accordance, the results of accuracy and RT were consistent, which indicated that the presence of the uncued color had an influence on the detection of the cued color. Even though, the two colors were clearly distinguishable.

3.2 EEG Results

3.2.1 P1

For analysis P1 peak amplitude, Mauchly's test of sphericity was significant on Electrodes and all interactions (p < .05), the significant values were reported based on the validated degrees of freedom. The results showed main effects of Electrodes ($F_{3,66}$ = 7.64, p = .001, $\eta_p{}^2$ = 0.26) and Search condition ($F_{2,44}$ = 8.29, p = .001, $\eta_p{}^2$ = 0.27). Pairwise comparisons of the Search condition (see Figure 3) showed smaller P1 peak amplitudes in the uncued condition relative to the cued condition (t_{22} = -4.72, p < .001, d = 0.98) and the neutral condition (t_{22} = -2.76, p = .034, d = -0.58), but no significant difference between the other two conditions (t_{22} = 1.05, p = .67). The interaction between Electrodes and Search condition was also significant ($F_{6,132}$ = 3.32, p = .016, $\eta_p{}^2$ = 0.13). The follow-up tests on separate electrode revealed that the simple effects of the Search condition were significant at P1/2 electrodes ($F_{2,44}$ = 7.86, p = .003, $\eta_p{}^2$ = 0.43), P3/4 electrodes ($F_{2,44}$ = 7.09, p = .004, $\eta_p{}^2$ = 0.40), PO3/4 electrodes ($F_{2,44}$ = 11.29, p < .001, $\eta_p{}^2$ = 0.52), but not the PO7/8 electrodes ($F_{2,44} = 2.15$, $p = .14$). No other main effect or interaction was observed ($p > .05$).

Mauchly's test of sphericity was significant on the interaction between Electrode and Search condition, as well as the three-way interaction ($p < .05$), For the analysis of peak latency of P1 component, neither main effect or interaction was found ($F < 1.5$, $p > .1$).

3.2.2 N1

Mauchly's test of sphericity showed significance on Electrode and interaction between Electrode and Search condition ($p < .05$). The main effect of Search condition was neither observed on the peak amplitudes ($F_{2,44} = 0.50$, $p = .61$) nor on the peak latencies ($F_{2,44} = 0.725$, $p = .49$).

3.2.3 N2pc

Mauchly's test of sphericity showed significance on Search condition was significant ($p > .05$). The N2pc area amplitude showed a remarkable main effect of Search condition ($F_{2,44} = 10.76$, $p = .003$, $\eta_p^2 = 0.33$). Pairwise comparison revealed that the mean amplitudes in the cued condition were more negative than amplitudes in the uncued condition ($t_{22} = -3.94$, $p = .002$, $d = -0.82$) and the neutral condition ($t_{22} = -3.62$, $p = .005$, $d = -0.75$). However, there was no difference between the uncued condition and the neutral condition ($t_{22} = 1.19$, $p =.75$). Additionally, paired-sample t-test of the area amplitude between the contralateral and ipsilateral electrodes showed significance in all levels of Search condition ($t_{22} = -4.94$, $p < .001$ for the cued condition; $t_{22} = -3.46$, $p = .002$ for the uncued condition; $t_{22} = -2.64$, $p = .015$ for the neutral condition)

3.2.4 P3

Mauchly's test of sphericity of peak amplitude showed significance on Electrode and interaction between Electrode and Search condition ($p < .05$), and of peak latency showed significance on interaction between Electrode and Search condition ($p < .05$). The 4 × 3 repeated-measures ANOVA on peak amplitude showed that both Electrode ($F_{3,66} = 4.19$, $p = .019$, $\eta_p^2 = 0.16$) and Search condition ($F_{2,44} = 7.13$, $p = .002$, $\eta_p^2 = 0.25$) revealed significant main effects.

Pairwise comparisons on Search condition indicated that the P3 peak amplitude in the neutral condition was smaller than that in the cued condition (t_{22} = 3.64, p = .003, d = 0.758) and the uncued condition (t_{22} = 3.58, p = .007, d = 0.75). However, the peak amplitudes were not significantly different between the cued and uncued condition (t_{22} = 0.51, p = .91). No significant interaction ($F_{6,132}$ = 1.38, p = .26) was observed. The same analysis was executed on the P3 peak latencies. The results showed that the main effects of the Electrode ($F_{3,66}$ = 1.54, p = .21) and of the Search condition ($F_{2,44}$ = 2.05, p = .14) were not significant. Interaction between the Electrode and the Search condition was also not significant ($F_{6,132}$ = 0.91, p = .50).

4 Discussion

The current study examined the influences of WM contents with distinct operations on selective attention. In this experiment, one of two memorized colors was cued to be maintained and the uncued one was supposed to be inhibited. These different processes exerted on WM contents have shown to differently modulate behavior and ERP indices of selective attention in a concurrent visual search task. Specifically, the behavioral responses to the search task were slowed down when the distractors were the maintained (cued) WM contents while speeded up when the distractors were the inhibited (uncued) WM contents, relative to performances in neutral condition. Consistently, these results were reflected in the results of ERPs indexing selective attention at early stage. An inhibitory process marked by smaller P1 amplitude was observed in the search task with the inhibited WM contents. Furthermore, the N2pc amplitude was larger with the maintained WM contents, indicative of a guidance effect. Herein, taking results of behavior and attention senstive ERPs together, we found that the selective attention was influenced by both the maintained and the inhibited WM contents. However, these influences by the maintained and the inhibited contents were different, corresponding to their separate operations during WM processing. Therefore, the operation-directed selection was supported that suggests the perceptually matching content is selected depending on its operation under executive attention. Interestingly, we found that the selective attention reflected in P3 as an attentioanl updating at late stage was equally modulated by the maintained and the inhibited WM contents.

Behavioral performance showed that the selective attention was separately modulated by the maintained WM contents and the inhibited WM contents because of different operations. Note that, both of the WM contents were memorized initially but then were cued to distinct operations. Thus, it was the operation of the contents that made them under executive attention and easily accessible, which is assumed to influence the attentional selection . Moreover, the influences by the maintained contents and the inhibited contents were different, demonstrating an adverse effect with the maintained WM content and a beneficial effect with the inhibited WM content. The distinct patterns of attentional effects were in line with the prediction of the operation-directed selection but not the attention-directed guidance. Therefore, we suggest that contents under executive attention affected visual attention depending on their ongoing operations. The present study goes beyond previous views by demonstrating that distinct operations of information separately determined selective attention to the matching content.

The results of ERPs further provided evidence to elucidate the mechanisms of the operation-directed selection. As for P1 component, it reflected inhibitory process of selective attention at the sensory gating stage . The inhibitory mechanism to filter out interference has been suggested in previous studies (Luck et al.,1994; Hillyard et al., 1998), with smaller P1 amplitude for targets presenting in the suppressed area. In current experiment, a smaller amplitude was observed in search array with the inhibited WM contents relative to that with the maintained WM contents and the neutral contents. The suppressed P1 component for the inhibited WM contents indicated that the contents were filtered out from visual attention in the search array. As the suppression of the inhibited WM contents, searching scope was narrowed down, facilitating search and showing a beneficial effect. Therefore, the electrophysiological modulation of the inhibited WM contents was consistent with the beneficial effect on behavior. Furthermore, the inhibitory mechanism to filter out specific content has also been observed during WM representation or utilizing a template for rejection , the processes of which resemble to the transfer of inhibitory operation of WM contents to perceptually matching contents. Thus, the P1 modulation implies that the inhibited WM contents were suppressed like the operation during WM.

Notably, the attentional guidance by the maintained WM contents was indicated by the N2pc amplitude, as what the previous studies have demonstrated . Here, the N2pc component was much larger in search array with the maintained content than that with the inhibited content and neutral contents, without difference between arrays with the inhibited contents and neutral contents. Thus, the guidance effect has been observed for the maintained WM contents but not for the inhibited WM contents. The guidance effect implies that the maintained WM contents captured visual attention, replicating the result of a related study by Kumar et al. (2009). As a result of attentional guidance, the maintained WM contents induced more distraction, hindering search for a target in the opposite place and resulting in an adverse effect on behavior. According to Desimone (1996), the search template is also kept in WM, thus that the attentional guidance by the maintained WM contents may resemble the selective attention directed by an active search template. Actually, the attentional guidance by the WM contents in the current dual task is different from that by a search template, because the former could be detrimental to the search task. Hence, in current study there might be a competition for selective attention after the guidance as Duncan and his cooperators have revealed . It is worthy to mention that a preliminary inhibition of the memory-relevant contents is inapposite in a dual task . Thus, the larger N2pc amplitude elicited by the maintained contents should reflect a competition for selective attention between the search target and the maintained WM content, revealing a re-deployment of attention to search target after a prior guidance in a neuroimaging study . In the meanwhile, it was reasonable with no sign of attentional guidance of the inhibited WM contents, since they were just suppressed at the sensory gate (P1 component). Taking together, the behavior performance is in accordance with the early ERP evidence, illustrating that it is the operation of the WM contents determines the selective attention of matching contents. We suggest that the operation-directed selection is probably due to a transfer of the inner operation to the perceptual selection on the same contents.

Moreover, findings of P3 amplitude provided convincing evidence to support that both the maintained and the inhibited WM contents were under executive attention. The P3 component is suggested to reflect a revision of mental representation induced by previous exposures in memory . The present results showed that the P3 amplitudes with the maintained and the inhibited WM contents were equal, but larger than that with the neutral contents. The larger P3 amplitude indicated that the visual scene with WM contents were updated, without distinction between the maintained and the inhibited contents. The updating of visual attention might be attributed to a requirement of shifting attentional focus , which had been occupied by WM contents previously. Hence, we considered that both the maintained and the inhibited WM contents were under executive attention, and that the different influences on selective attention of these contents can be resulted from their distinct operations. Notably, the attentional shifting, resulted from refreshing the visual context in attentional processing , helped to focus on the current search task.

However, the conclusion of operation-directed selection obtained here seems contradictory with a similar experiment by . Their results demonstrate an attentional guidance by the maintained WM items but no influence on selective attention by the inhibited WM items. The discrepant results between ours and could be due to difference of difficulty of the WM task. As we see, the WM stimuli used by Olivers et al. (2006) were of great similarity, which required precision visual representation and enhanced cognitive load. Thus, the high cognitive load leads to a loss of cognitive control, which may have hindered appropriate suppression of the task-irrelevant information (Lavie, 2000; Lavie et al., 2004; Rissman, Gazzaley, & D'Esposito, 2009; Roberts, Hager, & Heron, 1994; Sandrini, Rossini, & Miniussi, 2008). In the case, insufficient inhibitory operation of the uncued contents might account for the null effect on visual attention.
Nevertheless, in the current study we utilized relatively easy task and ensured the maintaining and inhibitory operation of the WM contents, showing distinct patterns of influence on selective attention and supporting the operation-directed visual selection.

The view of operation-directed visual selection contains two aspects, an influence of WM contents under executive attention and a selective attention determined by the operation of the contents. First of all, the attentional allocation is influenced by contents under executive attention, even for memory being retrieved . In other words, the once maintained contents or priming items cannot influence visual attention, since they are not under executive attention at that moment . However, executive attention is not so obvious in dual task, since the limitation of capacity and competition between goals, usually allowing the immediate goal to be attended in the focus of attention . Thus, facing an immediate search task, this influence occurs only when the attentional focus is dominated by the WM contents; otherwise, it will be absent. Secondly, we go beyond this view and propose that the direction of the attentional influence (attend vs. suppress) is determined by operation on the executive attention of the WM contents.

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