Concurrent working memory load can reduce distraction

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People have difficulty performing two tasks at once. For example, maintaining items in working memory (WM) makes people more distractible. However, different types of WM load may have different effects on attentional selection depending on whether WM load overlaps with mechanisms involved in target or distractor processing. Three experiments examined the effect of concurrent WM load on Stroop tasks, a widely used measure of executive control and inhibition. Stroop interference increased when the type of WM load overlapped with the type of information required for the target task (experiment 1). In striking contrast, Stroop interference decreased when the type of WM load overlapped with distractor processing (experiment 2). Experiment 3 replicated these results in a different Stroop task. Thus, concurrent WM load does not always impair executive control; performance depends on how contents of WM and task-relevant information overlap. The results highlight how dissociable components of WM interact with perception and executive control.

attention | executive control | Stroop interference | cognitive load

In the face of distracting information, attentional mechanisms help to prioritize and select information that is most relevant for current behavioral goals. However, selection is not perfect. Failure to inhibit unnecessary information (i.e., distractors) causes people to slow down and make mistakes. The Stroop interference effect is one of the most straightforward examples in which uninhibited distractor processing interferes with target processing. People are significantly slower to name the ink color of a colored word when the meaning of the colored word is incongruent with the ink color of the word (e.g., "red" in blue ink) as opposed to when it is congruent (1). Stroop and other researchers (2–4) explained this interference with the automaticity hypothesis: Word reading is more automatic than color naming. According to this account, the more arduous, attention-demanding process of color naming is hampered by the more automatic process of word reading (5). However, contrary to predictions from the word automaticity account, Stroop interference can be observed from color distractors in revised versions of the task (5, 6). Thus, a more general explanation of the Stroop effect simply focuses on the inability to ignore distractor information, which may vary in salience depending on the task. Stroop interference occurs whenever observers fail to inhibit distractor information that is incongruent with the target task and response.

An important goal of attention research is to understand the conditions that promote selection and reduce distractor interference. Given such robust interference in the Stroop task, are there manipulations to reduce interference? Stroop interference should be reduced if people's attention can be diverted away from the conflicting information. Indeed, an innovative study by Kahneman and Chajczyk (7) successfully reduced the Stroop effect by presenting additional distractors in the display, which served to reduce the perceptual salience of the color word. Thus, perceptual manipulations that decrease processing of distractors benefit attentional selection of targets. This logic is at the basis of perceptual load theory, which posits that one way to reduce processing of a stimulus is by increasing the perceptual load of a task (8–11).

Another mechanism that should influence attentional selection is working memory (WM). According to Baddeley's (12) influential model, the WM system contains a central executive that helps maintain and manipulate information in the mind, which is important for most cognitive tasks. WM systems are intimately intertwined with attentional selection mechanisms; for example, holding a spatial location in WM induces a shift in spatial attention to that location (13). Furthermore, dual-task impairments can be observed if WM load overlaps and conflicts with attentional processes required for a task, consistent with the common intuition that performance suffers when people try to do two or more tasks at once (14, 15). Specifically, loading spatial WM with irrelevant spatial information impairs performance in tasks, such as visual search, that require spatial attention (16, 17). Using a response conflict task, de Fockert *et al.* (18) demonstrated that a concurrent WM load increased the amount of response conflict from distractors. Load theory proposes that executive control processes require WM capacity to inhibit distractors, so taxing WM with other information impairs executive control, resulting in increased distractor interference (11, 18).

However, WM is not a unitary mechanism. In addition to the central executive, the WM system contains separate stores for verbal information and for visuospatial information (12, 19). Accordingly, loading WM should not always disrupt the efficiency of selective attention if the type of WM load does not overlap with processes required for the selective attention task. For example, a color WM load does not disrupt visual search for shapes (20), and a WM load of face targets does not disrupt background scene processing (21).

Motivated by these considerations, the present study examined the possibility that different types of WM load may have different effects on a concurrent Stroop task. Whereas prior work (11, 18) predicts that higher WM load should always impair selective attention processing by disrupting general cognitive control, we propose instead that the effects of WM load should depend on how the load overlaps with target and distractor processing in the selective attention task. In this study, we pursue this logic to make the even more extreme prediction that, rather than impairment, one may even observe improvement in target selection and distractor filtering under certain types of WM load. Our predictions are motivated by multiple resource theory, which posits that there are multiple, independent pools of resources and that tasks that share the same limited resource would interfere with each other but would not affect other tasks that require a different type of resource (22–24).

Specifically, maintaining a concurrent WM load that consumes resources required for target processing in a selective attention task will impair target selection. If the concurrent WM load consumes resources that are irrelevant to the selective attention task, then no impairment will be observed. The most interesting test comes when

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Abbreviations: WM, working memory; RT, response time.

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concurrent WM load overlaps with distractor processing. Load theory predicts that selective attention will be impaired, because any WM load disrupts cognitive control. However, we predict the counterintuitive result of improved selective attention, because the WM load will tie up limited capacity mechanisms required for distractor processing, reducing the potency (salience) of the distractors and, hence, the interference that they impose on the task.

Therefore, we used various WM loads and selective attention tasks to explore the interactions between WM and selective attention. Experiment 1 tested whether Stroop interference increased when WM load interfered with target processing. Experiment 2 examined whether Stroop interference was blocked when WM load interfered with distractor processing. Experiment 3 expanded the results from experiments 1 and 2 to a different Stroop task that involved spatial processing.

Experiment 1

Experiment 1 examined whether a meaning-comparison Stroop task would be disrupted by a WM load that taxed limited capacity mechanisms required for target processing. To carefully separate the type of cognitive process that was loaded in WM, we divided experiment 1 into two subexperiments. Experiment 1A imposed a verbal WM maintenance load together with a meaning-comparison Stroop task. We expected increased Stroop interference as a result of the verbal WM load tying up limited capacity mechanisms needed to process the meanings of the target words in the Stroop task. As a control, experiment 1B used a spatial information maintenance WM task together with the same Stroop task. Spatial WM load should have no effect on Stroop interference, because spatial information is not required for either target or distractor processing in the meaning-comparison Stroop task.

Experiment 1A. In the meaning-comparison Stroop task, participants decided whether the color of a patch was the same as the meaning of a colored word while retaining in WM seven letters that were randomly renewed in each trial (5). That is, participants had to use verbal mechanisms to process the meaning of the target word in the Stroop task and to retain the letters in WM. If the concurrent verbal WM load occupied verbal mechanisms needed for the Stroop task, the Stroop interference effect should be greater in the dual-task (WM load and Stroop task) condition than in the single-task (Stroop task only) condition.

Methods. Participants. Eighteen undergraduate students participated in exchange for course credit. For this experiment and all subsequent experiments, the subjects were from Yonsei University. All subjects had normal or corrected-to-normal vision and were naïve to the purposes of the experiments.

Stimuli and apparatus. All experiments in this study were run on a Pentium 4 PC, which was controlled by programs written in MATLAB with Psychophysics Toolbox extensions (25). Stimuli were presented on a 17-inch Flatron monitor (LG, Seoul) with an 85-Hz refresh rate (11.76 ms per frame). Participants looked at the screen from a distance of 57 cm using a chin rest and responded by pressing one of the prespecified keys on a computer keyboard.

Stimuli used in the Stroop task were a colored square patch and a colored word, each subtending a visual angle of 1.35° × 1.03°. These stimuli appeared 1.03° above and below central fixation. All stimuli were chosen randomly among one of five colors: red (RGB 255, 0, 0), blue (RGB 0, 0, 255), yellow (RGB 255, 255, 0), green (RGB 0, 255, 0), or purple (RGB 255, 0, 255). The colored word was also randomly selected among five color names: "red," "blue," "yellow," "green," or "purple" in Korean.

The letter display of the memory task consisted of seven characters chosen randomly among 14 Korean characters: "Ga," "Na," "Da," "Ra," "Ma," "Ba," "Sa," "Ah," "Ja," "Cha," "Ka," "Ta," "Pa," or "Ha." Each character subtended a visual angle of 0.88° × 0.88°, and all characters were equally spaced on a horizontal row at the center of the display. The order of the seven characters in the memory set and the character selected for the memory test display were also randomly chosen in each trial.

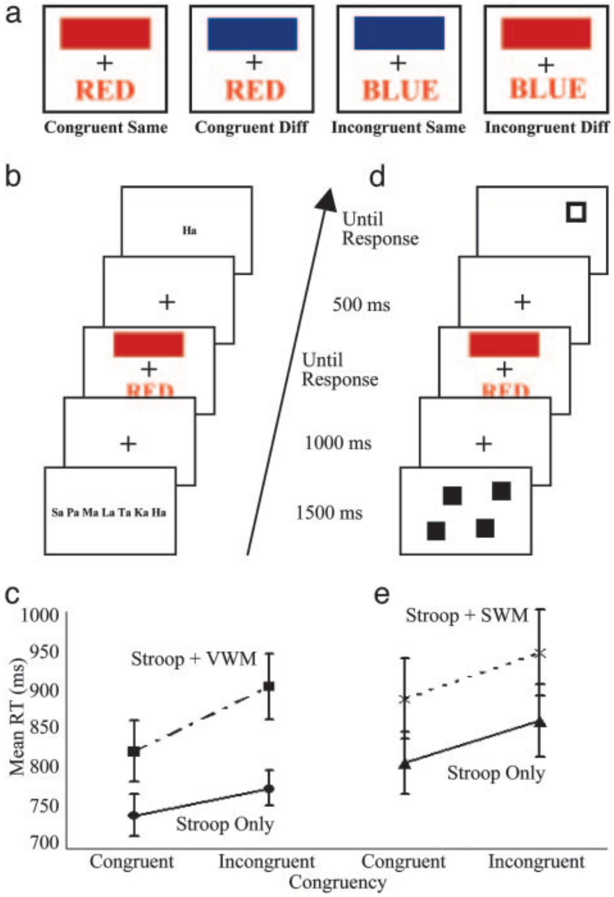

Fig. 1. Experiment 1: Target-relevant WM load increased Stroop interference. (*a*) The meaning-comparison Stroop task display conditions used in experiments 1A and 1B. (*b*) Schematic trial of experiment 1A, which required maintenance of verbal information while performing the meaning-comparison Stroop task. (*c*) Mean RTs for each condition in experiment 1A. Stroop interference, indicated by the slope difference between incongruent and congruent trials, increased in the dual-task condition compared with the single-task condition. (*d*) Schematic trial of experiment 1B, which required maintenance of spatial information while performing the meaning-comparison Stroop task. (*e*) Mean RTs for each condition in experiment 1B. Stroop interference did not differ between single- and dual-task conditions.

Experimental design. All experiments had two factors: task and congruency. The task factor was either the Stroop task-only condition or the dual-task condition, which consisted of maintaining a WM load while performing the Stroop task. The congruency factor also had two levels, either "congruence" or "incongruence." As shown in Fig. 1*a*, experiment 1A had four types of trials depending on the combination of congruency condition and the required response. The leftmost panel illustrates the congruent-same condition, in which the color of the colored patch, the meaning of the word, and the ink color of the word were all identical. The next panel to the right represents the congruent-different condition, in which the color of the colored patch and the meaning of the word were different, and the ink color of the word was also different from the color of the patch. The next panel to the right illustrates the incongruent-same condition, in which the color of the colored patch and the meaning of the word were identical, but the ink color of the word was different from the color of the patch. The rightmost panel is the incongruent-different condition, in which the color of the colored patch and the meaning of the word were different, but the ink color of the word was the same as the color of the patch.

Procedure. Fig. 1*b* illustrates the procedure. In the dual-task condition, participants initiated each trial by pressing the enter key, followed by 1,000 ms of WM task instructions, which read "remember the following letters." The instruction prompt was followed by a 1,000-ms fixation cross, and then seven randomized Korean characters were presented at the center of the display. Participants were required to remember those characters, and they expected to have a recognition test at the end of each trial. The memory array was presented for 1,500 ms, followed by a fixation cross for 1,000 ms. After the fixation disappeared and while the participants were maintaining the memory letters in WM, they were presented with the Stroop array that required a quick response to determine whether the color of the patch was the same as the meaning of the word that was presented below the patch. Subjects indicated either a same or different response by pressing the "same" ("K") or "different" ("M") keys on the computer keyboard with the middle and index fingers of their right hand, respectively. The response cleared the Stroop display, and then a fixation cross was presented for 500 ms, followed by the memory test display. To perform the memory test, participants had to decide whether the displayed character was one of the seven characters presented at the beginning of the trial. Subjects indicated either a yes or no response by pressing the "present" ("S") or "absent" ("X") keys on the computer keyboard with the middle and index fingers of their left hand, respectively. The memory test was displayed until the response, and then the next trial started immediately.

In the Stroop task-only condition, a 500-ms blank screen replaced the memory array, and the memory test display was removed. The dual-task and single-task conditions were tested in separate blocks. Each condition consisted of 4 practice trials and 40 experimental trials. The order of blocks was randomized across participants.

Results. For this experiment and all subsequent experiments, accuracy and mean correct response times (RTs) for the Stroop tasks were analyzed by using an ANOVA with task (dual task or Stroop task-only) and congruency (congruence or incongruence) as factors. Stroop task accuracy was comparable for the Stroop-alone condition (94.9%) and the dual-task condition (93.2%) [$F\,(1, 17) = 2.125$; $P > 0.16$]. In addition, accuracy did not differ between the congruent condition (94.9%) and the incongruent condition (93.2%) [$F\,(1, 17) = 2.125$; $P > 0.16$]. Importantly, there was no interaction between task and congruency ($F < 1$), ruling out speed–accuracy confounds in the RT analysis below. WM task accuracy was 84.4% correct. We included only trials that were correct for both the memory task and the Stroop task in the analyses for all subsequent experiments.

Fig. 1*c* shows the RT results. The RT analysis yielded highly significant main effects of congruency [$F\,(1, 17) = 25.011$; $P < 0.01$] and task condition [$F\,(1, 17) = 9.748$; $P < 0.01$]. More interestingly, there was a significant interaction between congruency and task condition [$F\,(1, 17) = 12.987$; $P < 0.01$], indicating that the Stroop interference effect was significantly greater in the dual-task condition (82 ms) than in the Stroop task-only condition (34 ms).

Experiment 1B. Experiment 1B tested the prediction that the Stroop effect would not be influenced by a WM load that is unrelated to either target processing or distractor processing. This test would rule out the possibility that the increased Stroop effect in experiment 1A was simply due to an increase in general difficulty and load. To test the specificity of WM load, the current experiment replaced the verbal information maintenance task with a spatial information maintenance task, which involved spatial processing in WM. Spatial WM should not tax mechanisms related to word or color processing. If so, spatial WM load should not affect the magnitude of Stroop interference, suggesting that the critical factor in experiment 1A was the specific processing overlap in limited capacity verbal mechanisms between WM and the Stroop task.

Methods. *Stimuli.* The stimuli for experiment 1B were identical to those used in experiment 1A except for the WM task. As shown in Fig. 1*d*, the stimuli used in this spatial WM task were small, black filled squares, each subtending a visual angle of .31° × .31°. A black empty square was also used as a probe for the recognition test.

Procedure. The single-task condition was identical to that used in experiment 1A. The procedure for the dual-task condition also matched experiment 1A, except that the verbal WM task was replaced with a spatial WM task (Fig. 1*d*). In the dual-task condition, instead of seven characters, participants were presented with four black filled squares whose locations were selected randomly from nine possible locations in each trial. Participants were asked to memorize the four locations. While holding the spatial information in their WM, they performed the meaning-comparison Stroop task. After responding to the Stroop task, one black empty square (a probe) was presented, and participants decided whether the location of the empty square was previously occupied by one of the black filled squares. If the probe was in the same location as one of the remembered four locations, participants were asked to press the "present" ("S") key. Otherwise, they were required to press the "absent" ("X") key.

Results. Eighteen subjects participated. Stroop task accuracy was comparable for the Stroop-alone condition (96.8%) and the dual-task condition (95%) [$F\,(1, 17) = 1.781$; $P > 0.20$]. In addition, the congruent condition (96.4%) and incongruent condition (95.4%) were similar ($F < 1$). Importantly, there was no interaction between task and congruency ($F < 1$), ruling out speed–accuracy confounds in the RT analysis below. WM task accuracy was 83.8% correct.

As shown in Fig. 1*e*, for RT, there were significant main effects of congruency [$F\,(1, 17) = 43.306$; $P < 0.01$] and task [$F\,(1, 17) = 7.463$; $P < 0.05$]. However, the interaction between the factors was not significant ($F < 1$), indicating that the Stroop interference was not significantly greater in the dual-task condition (58 ms) than in the single-task condition (54 ms).

Discussion of Experiment 1. Overall, experiments 1A and 1B demonstrated that Stroop interference in the meaning-comparison Stroop task increased with a verbal WM load but not with a spatial WM load. To further confirm these results, we conducted a three-way mixed ANOVA on RTs for the Stroop task in experiments 1A and 1B with congruency (congruent, incongruent) and task type (single, dual) as within-subject factors and with WM task type (verbal WM, spatial WM) as a between-subjects factor. This analysis yielded a significant three-way interaction among factors [$F\,(1, 34) = 5.384$; $P < 0.05$], indicating that the effect of WM load on the Stroop task depended on the type of WM that was occupied. Importantly, WM task performance did not differ between the two experiments ($F < 1$).

Thus, concurrent verbal WM load increased Stroop task interference when it taxed limited capacity mechanisms needed for verbal target processing in the meaning-comparison Stroop task because of increased interference from the distracting information. However, the equally difficult spatial WM load was irrelevant to either target or distractor processing, and so it did not yield any changes in the Stroop interference effect. Different types of WM load had different effects on the Stroop task.

Experiment 2

Whereas experiment 1 used a WM load that overlapped with target processing, experiment 2 examined the effects of a WM load that overlaps with distractor processing. In a color-comparison Stroop task, participants decided whether the ink color of a colored word was the same as that of a color patch presented above the word (26). In this Stroop task variant, the target required color perceptual processing, whereas the distractor involved verbal processing.

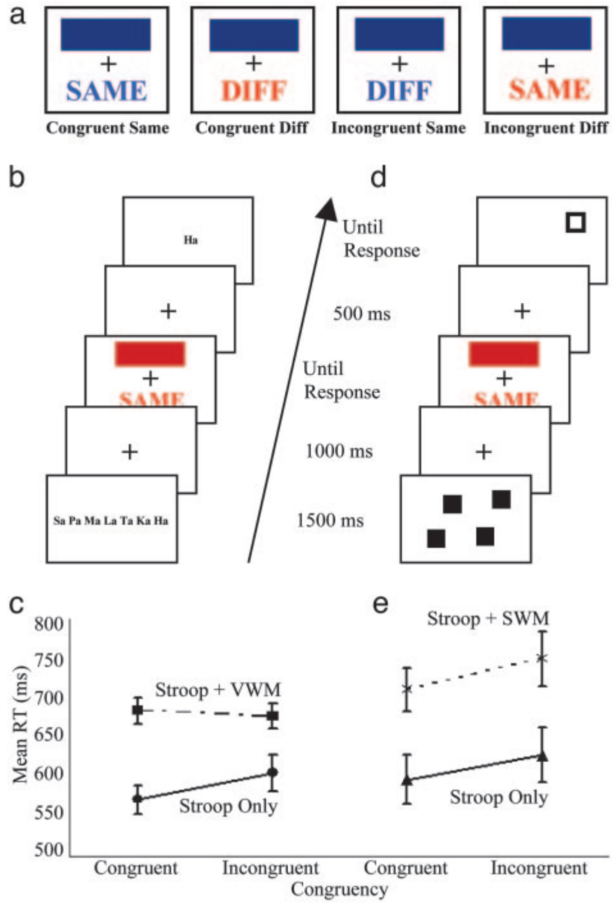

Fig. 2. Experiment 2: Distractor-relevant WM load decreased Stroop interference. (*a*) The color-comparison Stroop task display conditions used in experiments 2A and 2B. (*b*) Schematic trial of experiment 2A, which required maintenance of verbal information while performing the color-comparison Stroop task. (*c*) Mean RTs for each condition in experiment 2A. Stroop interference decreased in the dual-task condition. (*d*) Schematic trial of experiment 2B, which required maintenance of spatial information while performing the color-comparison Stroop task. (e) Mean RTs for each condition in experiment 2B. Stroop interference did not differ between single- and dual-task conditions.

Experiment 2A. Experiment 2A investigated the influence of verbal WM load on the color-comparison Stroop task (26). We predicted that Stroop interference should be decreased if the verbal WM load taxed the same limited capacity mechanisms used for distractor processing in this color-comparison Stroop task, which required participants to compare the color of a patch to the ink color of a colored word. Reduced processing of the colored word should reduce the interference it produces.

Methods. The stimuli, shown in Fig. 2*a*, were identical to those used in experiment 1A, except that the colored words in the Stroop task were "same" or "different" in Korean (each 1.35° × 1.03°).

The procedure, shown in Fig. 2*b*, was identical to that in experiment 1A, except that the meaning-comparison Stroop task was replaced with the color-comparison Stroop task. In the dual-task condition, participants performed the color-comparison Stroop task while holding a verbal load of seven letters in WM. They were required to press the "same" ("K") key if the color of the patch and the ink color of the word were identical regardless of the word meaning. If they were different, participants pressed the "different" ("M") key. In the Stroop task-only condition, tested in a separate block, a 500-ms blank screen replaced the memory array, and the memory test display was removed. Each condition consisted of 4 practice trials followed by 48 experimental trials.

Results. Eighteen subjects participated. Stroop task accuracy was similar for the Stroop-alone (97.9%) and dual-task (98.6%) conditions ($F < 1$) and for the congruent (98.3%) and incongruent (98.3%) conditions ($F < 1$). Importantly, there was no interaction between task and congruency ($F < 1$), ruling out speed–accuracy confounds in the RT analysis below. The mean accuracy for the WM task was 85.2%.

As shown in Fig. 2*c*, a two-way within-subject ANOVA of RT revealed significant main effects of congruency [$F(1, 17) = 5.766$; $P < 0.05$] and task [$F(1, 17) = 21.461$; $P < 0.01$]. Most importantly, the interaction between the factors was significant [$F(1, 17) = 11.658$; $P < 0.01$], showing that Stroop interference completely disappeared in the dual-task condition (−7 ms) compared with the Stroop task-only condition (34 ms).

Experiment 2B. The goal of experiment 2B was identical to that of experiment 1B, in which we predicted that the Stroop effect would not be influenced by a WM load that did not tax limited capacity mechanisms needed for either target processing or distractor processing. To investigate this, we imposed the spatial WM task from experiment 1B on the color-comparison Stroop task tested in experiment 2A.

Methods. Fig. 2*d* illustrates the procedure. The Stroop task stimuli used in experiment 2B were identical to those used in experiment 2A, and the WM task stimuli were identical to those in experiment 1B. Experiment 2B was identical to experiment 2A, except that we substituted the spatial WM task (identical to that used in experiment 1B) for the verbal WM task.

Results. Eighteen subjects participated. Stroop task accuracy was similar for the Stroop-alone (97.3%) and dual-task (98.5%) conditions [$F(1, 17) = 1.283$; $P > 0.27$], as well as for the congruent (97.6%) and incongruent (98.3%) conditions [$F(1, 17) = 1.288$; $P > 0.27$]. Importantly, there was no interaction between task and congruency [$F(1, 17) = 2.480$; $P > 0.13$], ruling out speed–accuracy confounds in the RT analysis below. The mean error rate for the WM task was 82.4%.

The RT results of this experiment, shown in Fig. 2*e*, were nearly identical to the results of experiment 1B. Significant main effects of congruency [$F(1, 17) = 15.810$; $P < 0.01$] and task [$F(1, 17) = 13.174$; $P < 0.01$] were observed, but the interaction between the two factors was not significant ($F < 1$). That is, there was no increase or decrease in the Stroop interference effect in the dual-task condition (32 ms) compared with the Stroop task-only condition (39 ms). Spatial WM load, related to neither target nor distractor processing in the color-comparison Stroop task, did not modulate the Stroop interference effect.

Discussion of Experiment 2. Experiments 2A and 2B confirmed the hypothesis that a WM load related to distractor processing in the Stroop task could even reduce Stroop interference. Specifically, when verbal WM load consumed limited capacity mechanisms required for the distractor, which involved verbal encoding of the words "same" or "different" in this color-comparison Stroop task, the salience of distractors was reduced, resulting in less interference (experiment 2A). This effect was not simply due to the general dual-task load, because an equally difficult spatial WM load, which should not engage the specific mechanisms used in target or distractor processing in this task, did not affect the Stroop effect (experiment 2B). This pattern was confirmed by a three-way mixed ANOVA on RTs with congruency (congruent, incongruent) and task type (single, dual) as within-subject factors and with WM task type (verbal WM, spatial WM) as a between-subjects factor. The RT results revealed a significant three-way interaction [$F(1, 34) = 8.279$; $P < 0.01$], indicating that the color-comparison Stroop interference was reduced only by verbal WM load and not spatial WM load. And yet, performance in both WM tasks did not differ from each other ($F < 1$).

The results of experiment 2 converge strongly with experiment

1. In experiment 1, the verbal WM load overlapped with target word processing, reducing capacity for the target, resulting in increased Stroop interference. In experiment 2, the verbal WM load overlapped with distractor word processing, reducing capacity for the distractor, resulting in decreased Stroop interference. Together, the results show that the effects of WM load on selective attention depend on how the type of WM load overlaps with limited capacity mechanisms needed for target processing or distractor processing. When there is overlap with target processing, selective attention is impaired; when there is overlap with distractor processing, selective attention is facilitated.

Experiment 3

Experiment 3 extended the results from experiments 1 and 2 to another type of Stroop task. Experiments 1 and 2 used Stroop tasks that involved verbal and color processing. The third experiment used a Stroop task that involved verbal and spatial processing. Participants were required to identify the meaning of a word ("right" or "left") while ignoring the orientation of a distractor arrow ("→" or "←") that was presented above or below the word. Hence, the target of this task was a word stimulus that required verbal processing. In contrast, the distractor was an arrow stimulus that required spatial processing.

Experiment 3A. Experiment 3A tested whether verbal WM load would increase the Stroop interference effect by interrupting the verbal processing of the target in the left/right-decision Stroop task. This experiment should generalize the findings from experiment 1A, in which a concurrent verbal WM load that overlapped with processing of the verbal target produced stronger Stroop interference.

Methods. *Stimuli and apparatus.* As shown in Fig. 3*a*, the Stroop stimuli were black-colored words and arrows. The words were either "right" or "left" in Korean, subtending a visual angle of 3.11° × 1.03°. The arrow stimuli were "→" or "←," with a size of 4.14° horizontally and 1.03° vertically. Both the orientation of the arrow and the meaning of the target word were selected randomly in each trial, and the arrow was also randomly presented either above or below the word. The WM stimuli used in experiment 3A were identical to those used in experiments 1A and 2A.

Procedure. Fig. 3*b* shows the procedure. Experiment 3A was identical to experiment 1A except for the Stroop task itself. For the Stroop task, participants were instructed to press the right ("/") key if the word was "right" or the left (".") key if the word was "left." In the dual-task condition, participants performed the left/right-decision Stroop task while maintaining a seven-letter array in their verbal WM. In the Stroop task-only condition, tested in separate blocks, participants performed only the Stroop task without a concurrent WM task. Each condition consisted of 4 practice trials followed by 20 experimental trials.

Results. Ten subjects participated. Stroop task accuracy was similar for the Stroop-alone (99.5%) and dual-task (98.5%) conditions ($F < 1$), as well as for the congruent (100%) and incongruent (98%) conditions [F (1, 9) = 3.273; $P > 0.10$]. Importantly, there was no interaction between task and congruency ($F < 1$). WM task accuracy was 85% correct.

Fig. 3*c* shows the results. RTs differed significantly for congruency [F (1, 9) = 132.447; $P < 0.01$] and task [F (1, 9) = 44.206; $P < 0.01$]. As expected, there was a significant interaction between congruency and task [F (1, 9) = 6.946; $P < 0.05$], indicating that the verbal WM task increased Stroop interference (91 ms) compared with when the Stroop task was performed alone (46 ms).

Experiment 3B. Experiment 3B aimed to extend experiment 2A, which showed reduced interference when WM load consumed the same limited capacity mechanisms used for distractor processing in the Stroop task. Here, we used the same left/right-decision Stroop task as in experiment 3A but imposed a spatial WM task.

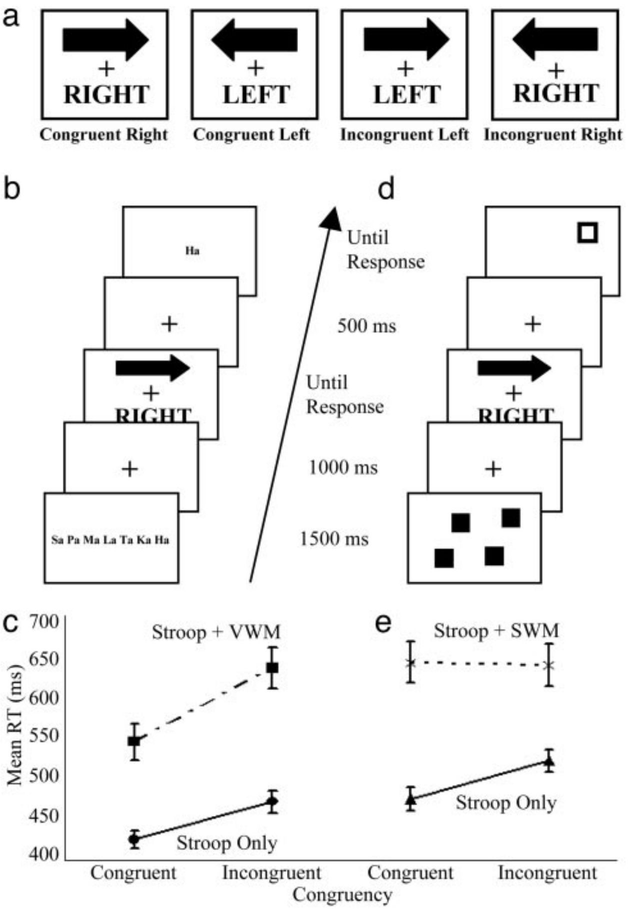

Fig. 3. Experiment 3: Target-relevant WM load increased Stroop interference, whereas distractor-relevant WM load decreased it. (*a*) The left/right-decision Stroop task display conditions used in experiments 3A and 3B. (*b*) Schematic trial of experiment 3A, which required maintenance of verbal information while performing the left/right-decision Stroop task. (*c*) Mean RTs for each condition in experiment 3A. Stroop interference increased in the dual-task condition. (*d*) Schematic trial of experiment 3B, which required maintenance of spatial information while performing the left/right-decision Stroop task. (e) Mean RTs for each condition in experiment 3B. Stroop interference decreased in the dual-task condition.

Methods. Fig. 3*d* shows the procedure. The Stroop task stimuli used in experiment 3B were identical to those used in experiment 3A, and the WM task stimuli were identical to those in experiment 1B. The procedure was identical to experiment 3A except that a spatial WM task replaced the verbal WM task.

Results. Ten subjects participated. Mean RT and accuracy were nearly identical to experiment 2A. Stroop task accuracy was not significantly different between the Stroop-alone (100%) and dual-task (98.5%) conditions [F (1, 9) = 3.857; $P > 0.08$] nor between the congruent (100%) and incongruent (98.5%) conditions [F (1, 9) = 3.857; $P > 0.08$]. The interaction between task and congruency was not significant either [F (1, 9) = 3.857; $P > 0.08$].

As presented in Fig. 3*e*, for RT, there was a significant main effect for congruency [F (1, 9) = 10.838; $P < 0.01$] and task [F (1, 9) = 51.537; $P < 0.01$]. The interaction between factors was also significant [F (1, 9) = 18.345; $P < 0.01$]. That is, the Stroop interference observed in the single-task condition disappeared when the spatial WM task was added. These results further demonstrate that a WM load related to distractor processing benefits selective attention processes in the Stroop task by reducing distractor processing (−3 ms) compared with when the Stroop task was performed alone (47 ms).

Discussion of Experiment 3. Experiments 3A and 3B replicated the results from previous experiments that demonstrated that different types of WM load yielded different effects on the Stroop tasks. When a verbal WM task was imposed, participants performed poorly in the verbal selective attention task, which led to increased Stroop interference (experiment 3A). In contrast, a spatial WM load reduced spatial distractor processing so that the Stroop interference effect disappeared in the dual-task condition (experiment 3B). To verify this pattern, we conducted a three-way mixed ANOVA on RTs from both experiments 3A and 3B with congruency (congruent, incongruent) and task type (single, dual) as within-subject factors and with WM task type (verbal WM, spatial WM) as a between-subjects factor. The results revealed a significant three-way interaction [F (1, 18) = 21.122; $P < 0.01$], validating our hypothesis. Importantly, WM performance did not differ between the two experiments ($F < 1$).

General Discussion

The present study investigated various effects of WM load on Stroop interference, a well known selective attention task. Six experiments demonstrated that different types of WM load produced different effects on Stroop interference. Specifically, Stroop interference increased when a verbal/semantic WM load impaired processing of a verbal/semantic target (experiment 1A and 3A). A notable result was that Stroop interference decreased when a verbal/semantic WM load disrupted processing of distractors defined by verbal/semantic information (experiment 2A). Experiment 3 replicated these results by showing that Stroop interference increased with a verbal WM load in a verbal/semantic target task and decreased with a spatial WM load in a task using spatial distractors. Furthermore, we demonstrated that Stroop interference was not affected by equally difficult WM loads that did not overlap with either target or distractor information (experiments 1B and 2B). The dissociation between the effects of different WM loads (i.e., verbal WM load vs. spatial WM load) on the Stroop interference effect supports our proposal that the efficiency of selecting a target and inhibiting a distractor depends on the relationship between the contents of WM and how it overlaps with target or distractor processing.

These beneficial effects of distractor-related WM load are surprising in light of other evidence that concurrent WM load should impair performance in a general manner. In prior behavioral and neuroimaging studies, high WM load increased distractor processing and interference in a selective attention task (11, 18). According to load theory, high WM load increases distractor interference by impeding inhibitory cognitive control over the interference from the irrelevant distractor. However, these previous studies only used WM loads that were related to target processing in their tasks. Accordingly, when we used target processing-related WM loads, we also observed increased interference in our Stroop tasks (experiments 1A and 3A). However, this dual-task impairment was not due to WM load *per se*, but the type of WM mattered. Selective attention was only impaired when the WM load consumed resources required for target processing, which was the case for the de Fockert *et al.* (18) study.

Thus, instead of positing that general WM load disrupts cognitive control (18), the present results are more compatible with a cognitive and neural architecture that contains dissociable systems for at least verbal, color, and spatial processing. Navon and Gopher (23) suggested the existence of modality-specific attentional resources. Also, since Baddeley (12) and his colleagues proposed an influential model of WM that postulated separate stores for visuospatial vs. verbal information, subsequent research has yielded numerous findings of neural divisions among verbal and visuospatial WM systems. For example, Smith *et al.* (19) observed a clear-cut double dissociation between verbal and spatial WM. The present results not only indicate that each system has its own independent attentional capacity (resources) but also provide previously unreported evidence that the same content-specific system subserves both WM and attentional selection, such that content-specific WM load affects the perceptual salience of related objects.

In conclusion, to understand how WM and attention interact, rather than drawing distinctions between the two, the focus should be placed on the type of information being processed (27). Concurrent WM load can either impair or benefit attentional selection, depending on how it overlaps with target or distractor processing. The significant finding that certain WM loads can actually reduce distraction may have implications for helping patients with inhibition dysfunctions, such as in attention deficit-hyperactivity disorder.

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