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The types of stimuli loaded in memory can modulate its effects on visual search

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The types of stimuli loaded in memory can modulate its effects on visual search

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The effects of memory load in visual search (VS) have shown a diversity of results from the absence through beneficial and detrimental effects of a concurrent memory load in VS performance. One of the hypotheses intended to explain the heterogeneity of results follows the idea proposed by certain models in the context of VS that the contents of working memory (WM) can modulate the attentional processes involved in VS (Desimone & Duncan, 1995; Duncan & Humphreys, 1989). In four experiments, we manipulated the similarity of information maintained in WM and those materials playing the role of target and distractors in the VS task. The results showed a beneficial effect in the first two experiments, where the materials in WM matched the target in VS. However, when they matched the distractors in the attentional task there is no effect in the slope of the search function. Present results strengthen those theories supporting that visual working memory is fractionated to allow for maintenance of items not essential to the attentional task (Downing & Dodds, 2004).

Keywords: Memory load; Selective attention; Visual search; Working memory.

The relationship between memory load and attentional processes in dual task conditions is one of the most important approaches to understand higher order cognitive functions in humans. Although many studies have shown the expected effect of impairment of memory load on attentional performance (de Fockert, Rees, Frith & Lavie, 2001; Gil-Gómez de Liaño & Botella, 2010; Hester & Garavan, 2005; Lavie, Hirst, de Fockert, & Viding, 2004; Rissman, Gazzaley, & D'Esposito, 2009), other studies have found less interference in the attentional task under high memory load conditions (Gil-Gómez de Liaño & Botella, 2011; Gil-Gómez de Liaño, Umiltà, Stablum, Tebaldi, & Cantagallo, 2010; Kim, Kim, & Chun, 2005; Kim, Min, Kim, & Won, 2006; Park, Kim, & Chun, 2007; SanMiguel, Corral, & Escera, 2008; Smilek, Enns, Eastwood, & Merikle, 2006), and still others have found no effects of memory load in attentional performance (Logan, 1978; Stins, Vosse, Boomsma, & de Geus, 2004; Woodman & Luck, 2007; Woodman, Vogel, & Luck, 2001). Those contradictory results have been a challenge to understand the nature of the processes involved.

In situations of *attentional capture*, the empirical evidence shows a wide convergence about the role of working memory in the guidance of attention. In a dual task paradigm where participants had to retain information in working memory while performing an attentional capture task, Downing (2000) found that attention was more probably captured by the items active in working memory. Jha (2002) found larger P1 and N1 ERPs components when the position of the target in the attentional task was the same as the position of the items held in the memory task. Likewise, Soto,

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Heinke, Humphreys, and Blanco (2005) found that the fixation in the attentional task, as measured by eye movements, was higher for the items held in working memory, suggesting an involuntary top-down directing of attention to a stimulus matching the contents of working memory. All those studies suggest that the items in working memory receive a selection advantage in terms of related relevant material over the irrelevant in attentional capture tasks. According to present findings, the Biased Competition Model (BCM) supports that the contents of working memory may lead to a modulation of attentional selection (Desimone & Duncan, 1995; Duncan & Humphreys, 1989).

However, in Visual Search (VS) tasks, a variety of results have been found. Some of the evidence supports the assumption that as memory load increases, attention to relevant material is impaired (Gil-Gómez de Liaño & Botella, 2010; Lavie & de Fockert, 2006), which fits the extended idea in the study of top-down attentional processes that as endogenous attention and working memory share cognitive resources, increasing the load of either process should impair the functioning of the other (Cowan, 1995). Other experiments, however, have failed to find the expected effect of memory load (Downing & Dodds, 2004; Logan, 1978; Woodman & Luck, 2007; Woodman et al., 2001), mostly arguing the flexibility of the cognitive system to sometimes inhibit or facilitate attentional mechanisms; and even others have found a more efficiency search under high memory load conditions (Smilek et al., 2006). The explanation that Smilek et al. (2006) gave to the results found was based on the idea that improved efficiency can result when reliance on slow executive control processes is replaced with reliance on more rapid automatic processes for directing attention during the search. In fact, they argue that the impact of cognitive load on the attentional set during the visual search can be mediated by a different cognitive strategy. As the amount of executive control available during the search task is reduced by holding certain information in working memory, the exogenous attentional system plays a more important role in performing the attentional visual search task, strengthening the idea that in VS both exogenous and endogenous attentional processes may take place (Wolfe, 1994). Nevertheless, using a very similar task to that used by Smilek et al. (2006), Woodman et al. (2001) did not find any effect of memory load in visual search.

There are two main differences between the studies of Smilek et al. (2006) and Woodman et al. (2001). The first one is the number of different distractors presented in the visual search task: Smilek et al. used only one type of distractor, whereas Woodman et al. presented two different distractors in the display for visual search. The second, and probably more important difference, is based on the information retained in the secondary memory task. Whereas Smilek et al. showed exactly the same items that played the role of the targets in the attentional task, Woodman et al. asked the participants to retain items that played the role of target or distractors in the visual search task. Following Smilek et al., if the amount of executive control available during the search task is reduced by holding certain information in working memory and the exogenous attentional system plays a more important role in performing the attentional visual search task, the experiments of both Smilek et al. and Woodman et al. should have shown a shallower set size function in the visual search for high memory load conditions. Only Smilek et al., however, found such an effect. It seems that the relationship between the items in the memory task and the target and distractors in the attentional task may play an important role in causing differential effects on attentional performance.

In fact, there have been several attempts to test if the relationship between information maintained in working memory and the information in the attentional task may help us to understand the variability data found, not only in Smilek et al. (2006) and Woodman et al.'s (2001) studies, but also in different studies in the context of VS. Chelazzi, Miller, Duncan, and Desimone (1993) found more activity in the inferotemporal cortex when the target was presented before the visual search using single-unit recordings in monkeys. The neurons responsive to the distractors, instead, were suppressed. Following the BCM and other models in the study of selective attention (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Treisman & Sato, 1990), the sensory inputs matching the contents of working memory will involuntarily capture exogenous attention. There has also been shown similar results in visual search tasks that strengthen the idea of an advantage of selection when information in working memory matches the target in the VS task (Smilek et al., 2006; Soto et al., 2005; Soto, Humphreys, & Heinke, 2006) even in neurological patients (Soto & Humphreys, 2006). However, as we have pointed before, a few researches have failed to find that effect (Woodman & Luck, 2007; Woodman et al., 2001). Moreover, when information held in working memory matches distractors presented in the visual search task, no modulation of memory load in the slope of the search function has been reported (Downing & Dodds, 2004), supporting the existence of a fractionated visual working memory that allow for maintenance of critical items that are not immediately relevant to the task. Therefore, although the relationship between information held in working memory and information in the visual search task has not always modulated effects of memory load in attentional performance, there is also strong evidence supporting the effect.

The present study pursues the idea that the effects of memory load in visual search could be modulated by the similarity between the material held in working memory and the material playing the roles of target and distractors in the visual search task. We hypothesise that if the information held in working memory is similar to the *target* in the visual search task, it will attract attention faster and, therefore, the slope of the search function will be shallower than in a single visual search task, as supported by many studies (Chelazi et al., 1993; Downing, 2000; Jha, 2002; Soto & Humphreys, 2006; Soto et al., 2005, 2006). We tested that hypothesis in the first two experiments. Experiments 1 and 2A basically replicate Smilek et al. (2006), changing only the critical differences with the procedure of Woodman et al. (2001) mentioned earlier (the relationship between material held in working memory and target or distractors in the attentional task). In both experiments, information in memory matches the target for the visual search, so we expect to find shallower slopes in the search function for the high memory load condition than for the single visual search task. We also conducted two more experiments (Experiments 2B and 3) where information held in memory matched the distractors of the visual search task. As we mentioned before, that manipulation was the one done by Downing and Dodds (2004) finding no effects of memory load in attentional performance. If the BCM model (Desimone & Duncan, 1995; Duncan & Humphreys, 1989) is right, we would expect to find a reversion of the effect; a poorer performance in the visual search task when memory is loaded with distractors of the attentional task, because they automatically may capture attentional demands. However, if Downing and Dodds are right and there is a fractionated visual working memory system that allows maintenance of critical items not relevant to the task (target), no modulation of memory load is expected in the slope of the search function of the visual search task.

EXPERIMENT 1

Method

Participants. Twelve undergraduate students, volunteers from the Autonomous University of Madrid, participated in the experiment. There were seven women and five men with a mean age of 18.8 (range 18–23), all reporting normal or corrected-to-normal vision.

Stimuli and materials. Stimuli and materials were based on Smilek et al.'s (2006) Experiment 2. Each display consisted of a target (circle with a gap on the left or right side) and one, three, or five distractors (circles with a gap both on the left and the right sides) as shown in Figure 1. Each item occupied one of eight possible locations, equally spaced on an imaginary circle centred on fixation. Item locations were randomly selected.

Displays were presented on a Pentium IV computer running E-Prime 1.2 experimental software (Schneider, Eschman, & Zuccolotto, 2002). The monitor resolution was 800×600 pixels and at this resolution items in the search display measured 0.8 cm in diameter and subtended a 0.8 degree visual angle at a viewing distance of 57 cm. The gaps in the distractor and the target items measured 0.15 cm. The imaginary circle on which the items were placed had a radius of 4.0 cm.

Procedure. An example of the procedure is shown in Figure 1. Each trial began with a fixation cross at the centre of the screen for 500 ms. Following a blank interval of 400 ms, a memory study display was presented for 1800 ms. In the dual task condition, participants were required to memorise the items in the study display. In the single task condition they had to ignore it. Then, the visual search display was presented for 2700 ms, followed by a blank interval of 400 ms. Participants' left index and middle fingers rested on the "z" key (gap on left side) and the "x" key (gap on the right side),

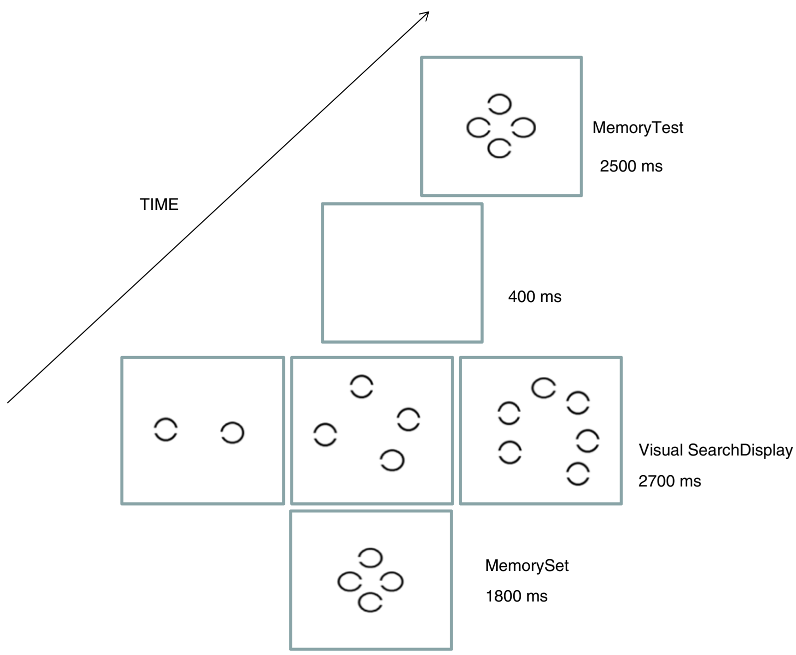

Figure 1. Procedure of Experiment 1.

which they pressed as soon as they identified the target. They were asked to respond as quickly as possible, but without sacrificing accuracy for speed.

Finally, a memory test display was presented for 2500 ms followed by a blank interval of 2000 ms before the beginning of the next trial. In the dual task condition, they had to report whether the memory test display was identical to or different from the memory study display, by pressing with their right hand either the "n" or the "m" key, respectively. The response to the memory test display was not speeded. In the single task condition they were required to press the "n" key to skip the memory test display, so advancing to the next trial.

Each participant was tested in a single experimental session consisting of two blocks of six practice trials (single and dual task) and two blocks of 180 experimental trials (one with the single task and the other with the dual task). The order of the single and dual task conditions was counterbalanced across participants. On the other hand, within each block, the three set sizes (2, 4, and 6) and the two targets (gap on the left vs. the right) yielded six possible combinations, which were repeated 30 times, with each display configuration determined randomly.

Results

Memory data. The memory task was completed with an overall accuracy of 84%. The percentages of correct responses were 84, 82, and 84 for set sizes 2, 4, and 6, respectively. In order to rule out a possible tradeoff between the memory and visual search tasks, we conducted a repeated measures ANOVA for the set size, finding no significant differences between 2, 4, and 6 set sizes, $F(2, 22) = 1.71$, $p = .20$, $\eta^2 = .135$. Therefore, as memory performance is the same regardless of the set size, the attentional results cannot be explained as a tasks tradeoff. All analyses in the attentional task are based on the trials with a correct response in the memory task.

Proportion of correct responses in visual search. Accuracy was analysed by means of a two-factor ANOVA with task (single or dual) and set size (2, 4, and 6) as within factors. There was a marginally significant effect of the task, $F(1, 11) = 4.28$, $p = .06$, $\eta^2 = .28$, whereas both the main effect of set size, $F(2, 22) = 0.22$, $p = .80$, $\eta^2 = .02$, and the interaction, $F(2, 22) = 2.06$, $p = .15$, $\eta^2 = .158$, were nonsignificant. Performance was better for the dual task condition (0.99 vs. 0.97; see Table 1).

Correct response time (RT). A new two-factor ANOVA with task and set size as within factors was

TABLE 1
Descriptive statistics for the visual search task in Experiment 1

	Proportion of correct responses						*Response time (RTs)*					
	Single task			*Dual task*			*Single task*			*Dual task*		
Items	*2*	*4*	*6*	*2*	*4*	*6*	*2*	*4*	*6*	*2*	*4*	*6*
Mean	0.98	0.99	0.97	0.99	0.99	0.99	763	949	1106	914	1038	1186
SD	0.02	0.02	0.03	0.01	0.02	0.01	179	210	220	156	157	155

conducted, this time on the average RTs of each condition and participant. The results show significant main effects of the task, $F(1, 11) = 6.85$, $p = .02$, $\eta^2 = .38$, and set size, $F(2, 22) = 181.22$, $p < .001$, $\eta^2 = .94$, as also of the interaction, $F(2, 22) = 8.50$, $p = .002$, $\eta^2 = .44$. Of course, the average RT was shorter for the single task than for the dual task condition (939 vs. 1046), and increased with set size (839, 994, and 1146, for the 2, 4, and 6 item conditions, respectively).

Our main interest, however, is in the significant interaction. As expected, the slope is shallower for the dual task than for the single task condition (68 vs. 86; see Table 2).[1]

Discussion

The results replicate those from Experiment 2 of Smilek et al. (2006). When memory is loaded the search function is shallower than in the single visual search condition. It can be explained as suggested by Smilek et al.: higher efficacy can result when reliance on slow executive control processes is replaced by reliance on more rapid automatic processes for directing attention during the search. That is what supposedly happens when some materials must be retained in working memory, as fewer resources associated with controlled processes are available for the search task.

If, however, the previous explanation is right, the results of Woodman et al. (2001) should have been similar, but they did not find any modulation of memory load in their visual search task. As advanced in the introduction, both results can be accommodated by taking into account the material composing the memory set and its relationship with the target and the distractors in the attentional task. Woodman et al. employed in the memory set the same items that played the roles of both target and distractors in the visual search. We can test our hypothesis by presenting the same items they used in their study but controlling their relationship with the target and distractors in the visual search.

Following Woodman et al.'s (2001) experiments, we employed circles with gaps on the left and right as distractors and circles with gaps up and down as targets. In Experiment 2A, however, the materials for the memory task were the same as those used for the target of the visual search (circles with gaps up and down), whereas in Experiment 2B the memory set was composed of the same stimuli used as the distractors in the attentional task (circles with gaps to the left or right). If our hypothesis was right, we expected to find a significant interaction between the task and the set size at least in Experiment 2A, showing as in Experiment 1 a shallower slope of the function under high memory load conditions. In Experiment 2B we might find no interaction (a disappearance of the effect found in Experiment 1 and presumably in Experiment 2A) following Downing and Dodds' (2004) suggestions (as shown in the introduction) or an interaction showing a reversion in the effect: a steeper slope of the function for the high memory load condition, as

TABLE 2
Mean search slope for each condition in all experiments

	Exp. 1	*Exp. 2A*	*Exp. 2B*	*Exp. 3*
Single task	86	96	72	73
Dual task	68	69	64	61

[1]Smilek et al. (2006) analysed their results employing the so-called Inefficiency Scores (Townsend & Ashby, 1983). The inefficiency scores combine RT and errors in a single measure of search inefficiency by dividing the correct mean RT of each participant by its correct mean proportion. They corrected the RT measure by its appropriate level of accuracy; when accuracy is perfect the inefficiency score equals the mean RT, but as accuracy decreases the inefficiency score increases proportionally to the errors. In order to be sure that any difference between our conclusions and those from them does not depend on using the raw average RT instead of the inefficiency, we redid the RT ANOVAs of Experiment 1 and the following experiments with the inefficiency scores. In all cases we found significant effects of the same factors as with the raw averages of RTs.

we pointed out in the introduction following the BCM (Desimone & Duncan, 1995; Duncan & Humphreys, 1989).

EXPERIMENT 2A

Method

Participants. Ten undergraduate students, volunteers from the Autonomous University of Madrid, participated in the experiment. They were all women, with a mean age of 20 (range 18–33), all reporting normal or corrected-to-normal vision.

Stimuli, materials, and procedure. Four circles with up and down gaps were presented in the memory task. The same types of stimuli were employed as targets in the attentional task, and the distractors were circles with a left or right gap. The main difference from Woodman et al.'s (2001) study was that the material held in working memory for their experiments could also be circles with left and right gaps, also matching distractors of visual search. The participant's task in the visual search was the speeded detection of a circle with a gap up (pressing the "s" key) or down (pressing the "x" key) instead of left and right (Experiment 1 task). Everything else remained the same as in Experiment 1.

Results and discussion

Memory data. The memory task was completed with an overall accuracy of 83%. The percentages of correct responses were 84, 82, and 83 for set sizes 2, 4, and 6, respectively. As in Experiment 1, any possible tradeoff between the tasks was excluded by conducting a repeated measures ANOVA for the set size, and finding nonsignificant differences between 2, 4, and 6 set size conditions, $F(2, 18) = 0.09$, $p = .91$, $\eta^2 = .01$. Again, the analyses in the attentional task are based only on the trials with a correct response in the memory task.

Proportion of correct responses in visual search. Accuracy was again analysed by using an ANOVA with task (single or dual task) and set size (2, 4, and 6) as within factors. The results reveal a main effect of the task, $F(1, 9) = 6.27$, $p = .034$, $\eta^2 = .411$, but not of the set size, $F(2, 18) = 0.76$, $p = .84$, $\eta^2 = .02$, or the interaction, $F(2, 18) = 1.26$, $p = .31$, $\eta^2 = .12$ (see Table 3).

Correct response time (RT). Again an ANOVA with task and set size as within factors was conducted. The results show significant main effects of the task, $F(1, 9) = 13.95$, $p = .005$, $\eta^2 = .61$, and the set size, $F(2, 18) = 73.65$, $p < .001$, $\eta^2 = .89$, as also of the interaction, $F(2, 18) = 14.83$, $p < .001$, $\eta^2 = .62$.

The average RT was shorter for the single task than for the dual task condition (941 vs. 1098), and increased with set size (851, 1026, and 1181, for the 2, 4, and 6 item conditions, respectively). As expected, again the nature of the interaction is that the slope is shallower for the dual task than for the single task condition (69 vs. 96; see Table 2).

The results of Experiment 2A are very similar to those of Experiment 1, and support our hypothesis. When the information employed in a secondary memory load task is similar to that playing the role of the target in the visual search task, the search function shows a smaller effect of the number of items in the display than in the single task condition. Present findings support the BCM and other models in the study of selective attention (e.g., Duncan & Humphreys, 1989; Treisman & Sato,

TABLE 3
Descriptive statistics for the visual search task in Experiments 2A and 2B

	Proportion of correct responses						*Response time (RTs)*					
	Single task			*Dual task*			*Single task*			*Dual task*		
Items	*2*	*4*	*6*	*2*	*4*	*6*	*2*	*4*	*6*	*2*	*4*	*6*
Experiment 2A												
Mean	0.98	0.98	0.98	0.99	0.997	0.99	749	940	1133	952	1112	1229
SD	0.02	0.01	0.01	0.01	0.01	0.01	79	129	169	161	179	194
Experiment 2B												
Mean	0.97	0.98	0.97	0.99	0.985	0.986	644	783	931	787	889	1041
SD	0.04	0.01	0.03	0.01	0.02	0.01	132	197	269	134	184	215

1990), suggesting that the sensory inputs matching the contents of working memory will involuntarily capture exogenous attention.

EXPERIMENT 2B

Method

Participants. Ten undergraduate students, volunteers from the Autonomous University of Madrid, participated in the experiment. They were all women, with a mean age of 22.3 (range 18–33), all reporting normal or corrected-to-normal vision.

Stimuli, materials, and procedure. Experiment 2B is identical to Experiment 2A with only one exception. Specifically, the stimuli employed for the memory task in the dual task condition were circles with a gap at the left or the right; that is, they were stimuli similar to those employed as distractors in the visual search task.

Results and discussion

Memory data. The memory task was completed with an overall accuracy of 78%. The percentages of correct responses were 78, 79, and 77, for set sizes 2, 4, and 6, respectively. As in Experiment 1, any possible tradeoff between the tasks was excluded by conducting a repeated measures ANOVA for the set size, finding no significant differences between 2, 4, and 6 set size conditions, $F(2, 18) = 1.09$, $p = .358$, $\eta^2 = .02$. Again, the analyses in the attentional task were based only on the trials with a correct response in the memory task.

Proportion of correct responses in visual search. Accuracy was again analysed by using an ANOVA with task (single or dual task) and set size (2, 4, and 6) as within factors. We found a significant main effect of the task, $F(1, 9) = 7.21$, $p = .025$, $\eta^2 = .445$, but not of the set size, $F(2, 18) = 0.143$, $p = .87$, $\eta^2 = .02$, or the interaction, $F(1.2, 10.8) = 0.91$, $p = .38$, $\eta^2 = .09$ (see Table 3).

Correct response time (RT). Again an ANOVA with task and set size as within factor was conducted. The results show significant main effects of the task, $F(1, 9) = 21.68$, $p = .001$, $\eta^2 = .71$, and the set size, $F(1.1, 9.6) = 50.71$, $p < .001$, $\eta^2 = .85$. There is, however, no significant effect of the interaction, $F(2, 18) = 0.86$, $p = .44$, $\eta^2 = .09$.

The average RT was shorter for the single task than for the dual task condition (786 vs. 906), and increased with set size (716, 836, and 986, for the 2, 4, and 6 item conditions, respectively). The slopes of the search functions were 72 and 64 for the single task and dual task conditions, respectively, as we can see in Table 2. They are statistically indistinguishable, as reflected in the nonsignificant interaction of the main factors.

The results of Experiment 2B are different from those of Experiments 1 and 2A. When the information employed in a secondary memory load task is similar to that presented as distractors in the visual search task, the search function shows a comparable effect of the number of items in the display as in the single task condition. In order to support more firmly the differences between Experiments 2A and 2B we conducted a three-way ANOVA ($2 \times 3 \times 2$) with task and set size as within factors and experiments (2A and 2B) as the between factor. For proportion of correct responses there was only a main effect of the task, $F(1, 18) = 13.17$, $p = .002$, $\eta^2 = .42$; however, for correct response time (RT) there was a main effect of all variables: task, $F(1, 18) = 31.51$, $p < .001$, $\eta^2 = .64$; set size, $F(2, 36) = 123.13$, $p < .001$, $\eta^2 = .87$; and experiment, $F(1, 18) = 5.98$, $p = .02$, $\eta^2 = .25$. There was also an interaction between task and set size, $F(2, 36) = 7.25$, $p = .002$, $\eta^2 = .29$, but more importantly, although only marginally, the three-way interaction was significant, $F(2, 36) = 2.91$, $p = .06$, $\eta^2 = .14$.

Although no interaction has been found in Experiment 2B (a steeper slope under high memory load conditions also could be expected), there has been a main effect of experiment and a three-way marginal interaction ($p = .06$) between Experiments 2A and 2B. It seems to show differential effects in visual search depending on whether the information in working memory is related to the target or the distractors in the visual search. When information in working memory is related to the target (Experiment 2A and Experiment 1), the attentional effect is smaller than in a single visual search task supporting our hypothesis. On the other hand, if information in working memory is related to the distractors (Experiment 2B), the search function is statistically indistinguishable from a single task condition, showing different effects from those in previous experiments.

According to the BCM (Duncan & Humphreys, 1989) we should have found not only a disappearance of the effect found in previous experiments but also a reversed interaction because of the automatic capture of attention guided by information maintained in working memory in Experiment 2B; showed up by a steeper slope under high memory load conditions. Though, we have found the same slope of the function under both single and dual task conditions, pointing to the theory that there must be a fractionated working memory that allow for maintenance of critical items not immediately relevant to the task following Downing and Dodds (2004).

However, as Smilek et al. (2006) found there was a more efficient search under memory load conditions only when search was hard but not when search was easy. They found no differential effects in VS under memory load conditions. Perhaps, Experiment 2B's task is not difficult enough to produce a modulation of memory load in the visual search task. In fact, RTs are faster in Experiment 2B compared to those found for Experiments 1 and 2A (see Tables 1 and 3). In order to test this hypothesis we conducted Experiment 3. As it is known that difficulty of the search increases when the similarity between nontargets decreases (Duncan & Humphreys, 1989), we replicated Experiment 2B, but introduced a higher *heterogeneity* in the memory set and the distractors of the visual search task in Experiment 3. If Smilek et al. are right, we should find a shallower slope of the function for the high memory load condition in Experiment 3 by increasing the difficulty of the task. On the contrary, if the relationship between contents in WM and distractors in the VS task is explaining the lack of an interaction between the factors, we should replicate Experiment 2B results.

EXPERIMENT 3

Method

Participants. Ten undergraduate students, volunteers from the Autonomous University of Madrid, participated in the experiment. Three men and seven women, with a mean age of 17.8 (range 17–18), all reporting normal or corrected-to-normal vision.

Stimuli, materials, and procedure. Experiment 3 replicates Experiment 2B with only one exception. Specifically, circles with gaps in both left and right sides (like distractors in Experiment 1) could be included within the stimuli employed for the memory task in the dual task condition and for the distractors in the visual search task. Therefore, we included one more distractor, increasing the heterogeneity of distractors both in memory load and in visual search.

Results and discussion

Memory data. The memory task was completed with an overall accuracy of 82%. The percentages of correct responses were 83, 82, and 82, for set sizes 2, 4, and 6, respectively. As in previous experiments, any possible tradeoff between the tasks was excluded by conducting a repeated measures ANOVA for the set size, finding no significant differences between 2, 4, and 6 set size conditions, $F(2, 18) = 0.08$, $p = .93$, $\eta^2 = .03$. Again, the analyses in the attentional task are based only on the trials with a correct response in the memory task.

Proportion of correct responses in visual search. The corresponding ANOVA with task (single or dual task) and set size (2, 4, and 6) as within factors revealed significant main effects of the task, $F(1, 9) = 10.37$, $p = .01$, $\eta^2 = .535$, and the set size, $F(2, 18) = 5.01$, $p = .02$, $\eta^2 = .358$, but not of the interaction, $F(2, 18) = 2.81$,; $p = .09$, $\eta^2 = .238$ (see Table 4).

Correct response time (RT). Again an ANOVA with task and set size as within factor was conducted. The results show significant main effects of the task, $F(1, 9) = 17.98$, $p = .002$, $\eta^2 = .666$, and the set size, $F(1.2, 10.5) = 67.18$, $p < .001$, $\eta^2 = .88$, but not of the interaction, $F(2, 18) = 2.82$, $p < .086$, $\eta^2 = .239$.

The average RT was shorter for the single task than for the dual task condition (789 vs. 951), and increased with set size (732, 879, and 1000, for the 2, 4, and 6 item conditions, respectively). The slopes of the search functions were 61 and 73 for the dual task and single task conditions, respectively (see Table 2). As in

TABLE 4
Descriptive statistics for the visual search task in Experiment 3

	Proportion of correct responses						*Response time (RTs)*					
	Single task			*Dual task*			*Single task*			*Dual task*		
Items	*2*	*4*	*6*	*2*	*4*	*6*	*2*	*4*	*6*	*2*	*4*	*6*
Mean	0.97	0.99	0.99	0.995	0.996	0.998	645	783	938	819	974	1061
SD	0.02	0.01	0.01	0.01	0.01	0.006	84	136	187	108	180	190

Experiment 2B, they are statistically equivalent, as reflected in the nonsignificant interaction of the main factors.[2]

The results of Experiment 3 are similar to those of Experiment 2B and different from those of Experiments 1 and 2A. When the information employed in a secondary memory load task is similar to that presented as distractors in the visual search task, even when the heterogeneity of those stimuli is increased, the search function shows a slope statistically indistinguishable from that of the single task condition.

GENERAL DISCUSSION

The main goal of the present study was testing an explanatory hypothesis for the heterogeneous results found when adding a concurrent memory load task in a visual search task. Sometimes a significant interaction has been reported, reflecting different slopes of the search function (steeper or shallower functions depending on the study) under the presence/absence of the memory load task. In other experiments, however, no interaction has been found. One of the most important hypothesis supported in the present and other studies is based on the relationship between information maintained in working memory and information in the attentional task. Present data as well as data shown in many other studies (Chelazzi et al., 1993; Smilek et al., 2006; Soto & Humphreys, 2006; Soto et al., 2005, 2006) support the hypothesis suggested, at least when information retained in working memory is related to the target in the visual search task: if information retained in working memory is similar to the target in the visual search task, it seems to capture attention and, therefore, the interference from the distractors is smaller than in a single visual search task. As expected, in Experiments 1 and 2A, in which the items in the memory task were similar to the target of the visual search, we found a significantly shallower slope of the function in the memory load condition than in the single task condition. Apparently, the attentional effect of set size is attenuated by maintaining the target active in working memory. As different attentional capture studies have previously shown (e.g., Downing, 2000; Soto et al., 2005), the exogenous component of attention benefits by having the target items active in working memory and the selection of the target is less impeded by the distractors in the task.

In contrast, in Experiments 2B and 3 the information retained in working memory was similar to the distractors of the visual search task. According to our hypothesis, we may find an interaction showing a reversion in the effect: if attention is automatically captured by the distractors we should find a less efficient search and, therefore, a steeper slope of the function for the high memory load condition. However, we have found that the search functions were statistically equivalent in both conditions, as reflected by the lack of a significant interaction between memory load and set size in both Experiments 2B and 3 (as we have also seen, there were not significant differences either between the slopes of the single and dual task conditions in both experiments). No interaction showing a steeper slope function under the high memory load condition has been found. As we pointed out before, results of Experiment 2B may have been explained in terms of the difficulty of the task: As reflected by RTs, the task may be easily enough to not produce any modulation of memory load in visual search, as also pointed by Smilek et al. (2006). We conducted Experiment 3 in order to

[2] As the *p*-value for the interaction may be considered as a marginally significant effect ($p = .086$), we conducted a *t*-test analysis on the slope values of the single and dual task conditions in order to strengthen the results found for RTs. The results showed that there were no differences between the slopes of the search function in Experiment 3, $t(9) = 1.38$, $p = .20$. Moreover, analysing differences between slopes for all experiments we found $p < .01$ for Experiments 1 and 2A, and $p = .40$ for Experiment 2B, again strengthening our hypothesis.

test it by making the search more difficult including a higher heterogeneity of distractors and loaded memory using that diversity of items. However, the results show no differences in the slopes of the single and dual task conditions. In fact, other studies have previously reported similar data. When information in working memory fits the distractors in the VS task there is no modulation of memory load in VS efficiency (Downing & Dodds, 2004; Moores & Maxwell, 2008). One of the most plausible explanations for present results has been proposed by Downing and Dodds (2004), suggesting the existence of two general models: one in which a representation of the current task biases the competition between items in a unitary Visual Working Memory (VWM) (results supported in our Experiments 1 and 2A and in previous studies manipulating working memory and target information in VS), and one in which VWM is fractionated to allow for maintenance of critical items that are not immediately relevant to the task. In other words, although the distractors in Experiments 2B and 3 may have automatically captured more attention because they were active in working memory (those items that had to be recognised at the end of the trial), that capture is not enough strong as in Experiments 1 and 2A to show more interference than in the single task condition because *they are not relevant* to the purpose of the task. In general, when information in working memory is the same as the target in the attentional task (Experiments 1 and 2A) the exogenous component of attention is benefited by having the target items active in working memory and the selection of the target is less impeded by the distractors in the task, as proposed by the BCM model. When, however, information in working memory fits the distractors of visual search, the exogenous component of attention is not benefited because the distractors are not relevant for the purposes of the task (searching the target) and they just show the same interference as in the single task, in contrast to what may be expected by the BCM model.

On the other hand, we could also say that results of the four experiments do not support the hypothesis of Smilek et al. (2006), based on the idea that the impact of cognitive load (whether or not there is a relationship between WM contents and visual search stimuli) on the attentional set during the visual search can be mediated by a different cognitive strategy. If this had been true, we should have found similar results in all four experiments. The relationship between information retained in WM and information in the VS task seem to be a key variable explaining the differential results. However, if we take into account the mean results of present experiments, we could see that the slopes for the load conditions in Experiment 2A and Experiment 2B are parallel, but the slopes for the no load conditions for both experiments diverge, with 2A showing a steeper slope than in Experiment 2B. That seems to show that it is not clear that the effect is only occurring in the high load conditions. As the manipulation is exactly the same in all experiments (1 and 2A; and 2B and 3) for the single task condition, there are no reasons to expect the differential results found, mainly if we think that the single and dual task conditions are blocked. Perhaps a differential attentional set or a strategy could account for the results found. Other researchers have proposed that the effects found in different experiments shown before may be explained by a strategic use of attention instead of an automatic capture of attention due to active information retained in working memory (Woodman & Luck, 2007). In fact, that idea follows the suggestion proposed by Smilek et al. (2006). However, if there is a differential attentional set or a strategic use of attention, it seems to be also mediated by the relationship between active information in WM and that playing the roles of target or distractor in the VS task (otherwise, we should have found the same results in the four experiments, as we have already mentioned). Perhaps the idea proposed by Smilek et al. of a more automatic search when memory is loaded, is occurring only when the contents of WM are similar to the target in the VS task. Therefore, it seems that the modulation of the variable exists although more research is needed to determine how this variable may modulate and explain differential effects in attentional performance in a VS task. Probably, a coherent next step would be to do a meta-analysis in order to determine how the variable affects attentional processes in VS. Moreover, in other experiments in the context of endogenous attention the same variable has been postulated to explain similar results although in an opposite way (Gil-Gómez de Liaño & Botella, 2011; Gil-Gómez de Liaño, et al., 2010; Kim et al., 2005). Even though a Stroop-like task may not be comparable to a VS task regarding the attentional processes immersed, data found in those studies may give more clues to understand the relationships between working memory and attention and the implication of the relationship between information retained in WM and information in the attentional task.

To conclude, present research contribution shows more evidence about the involvement of the relationship between information in WM and in a VS task by modulating attentional processes immersed in the task. Present data seem to support those data found by Downing and Dodds (2004) showing that the variable seems to modulate attentional processes only when it fits the purposes of the task (that is, when information in WM fits target in the VS task). However, the attentional advantage disappears when information in WM fits the distractors of the VS task. Also, other results have to be explained to determine how this variable modulates attentional processes in VS. As we suggested earlier, the present results as well as those found in other studies suggest that the variable is a key point to understand attentional performance in VS, although more research is needed to better understand those relationships.

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